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MEDICAL IMPLICATIONS OF LASERS
ON THE MODERN BATTLEFIELD

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE

by

WILLIAM J. KLENKE, MAJ, USA
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M.A., Webster College, 1979

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Fort Leavenworth, Kansas
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
1 June 1990

3. REPORT TYPE AND DATES COVERED
Master's Thesis,8-1989-6-1990

4. TITLE AND SUBTITLE
Medical Implications of Lasers on the Modern Battlefield

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Command and General Staff College
Attn: ATZL-SWD-GD
Fort Leavenworth, KS 66027-6900

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT (Maximum 200 words)
This thesis examines the impact on medical units caused by the proliferation of lasers on today's battlefields; it demonstrates that a significant number of casualties are possible and shows the need for more rigorous modeling to quantify and characterize them. One important conclusion is that the major impact of laser weapons will be on the tactical commander, not the medical unit. The commander must recognize and understand the effect of the laser battlefield on soldiers, units, and leaders. Training, preparation, and appropriate tactics are necessary to conserve the unit's strength for the decisive action. Three engagements (light, armor-augmented light, and heavy battalions) are defined using the TRADOC Common Training Scenario and the CGSC Tactical Commanders Development Course (TCDC) computer simulation. The Lawrence Livermore National Laboratory Air Defense Weapons model determined the laser's propagation. Each engagement was studied to estimate the number of laser casualties. The bibliography provides an extensive review of unclassified documents dealing with lasers and directed energy weapons. Specific areas investigated include tactical and medical laser-related doctrine, the status of laser technology and deployment, and threats, bioeffects, and the availability of medical support. (KR)

14. SUBJECT TERMS
laser, bioeffects, directed-energy, medical

15. NUMBER OF PAGES
131

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
U	U	U	UL

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9004622

MASTER OF MILITARY ART AND SCIENCE

THESIS APPROVAL PAGE

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

MEDICAL IMPLICATIONS OF LASERS ON THE MODERN BATTLEFIELD by Maj William J. Klenke, USA, 131 pages.

This thesis examines the impact on medical units caused by the proliferation of lasers on today's battlefields; it demonstrates that a significant number of casualties are possible and shows the a need for more rigorous modeling to quantify and characterize them.

One important conclusion is that the major impact of laser weapons will be on the tactical commander, not the medical unit. The commander must recognize and understand the effect of the laser battlefield on soldiers, units, and leaders. Training, preparation, and appropriate tactics are necessary to conserve the unit's strength for the decisive action.

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The bibliography provides an extensive review of unclassified documents dealing with lasers and directed energy weapons. Specific areas investigated include tactical and medical laser-related doctrine, the status of laser technology and deployment, and threats, bioeffects, and the availability of medical support. A brief history of the efforts by the USSR's and U.S.'s to develop laser weapons and the status of current military laser technology is also inserted.

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Unannounced	☐
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Distribution/	
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A-1	

INSPECTED 4

ACKNOWLEDGMENTS

I wish to thank--

COL Catherine H. T. Foster for her detailed comments, attention to detail, emphasis on quality, and moral support.

LTC Orville T. Stokes and MAJ Robert J. Matthews, TRADOC Program Integration Office-Technology Exploitation, for their advice and access to files.

MAJ James M. Adams, my Thesis Committee Chairman, for keeping me on focus and on time.

Vaughn DeLeath Neeld, editor, for many long hours.

The late COL S. Edwin Beatrice, Commander, Letterman Army Institute of Research and his staff for four years of technical support concerning lasers.

My family, for their understanding and love.

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CHAPTER 1

INTRODUCTION

BACKGROUND

There is a pressing need to increase our understanding of the medical impact lasers will have on the modern battlefield. Lasers are on the battlefield in large numbers now. Adjunctive lasers (rangefinders, designators, and other lasers intended as nonlethal components of a weapons system) have been fielded in large numbers and could be used directly as weapons.[1,2] Third World nations, as well as NATO and WARSAW Pact nations, have (or can easily get) laser systems and technologies.[3,4] The technology is now mature enough to make laser weapons. As recent studies have shown, most of the Army is not prepared to cope with the effects of lasers in combat.[5,6,7,8]

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[1] John Alexander, "Antimateriel Technology," Military Review, October 1989, p. 29-30.

[2] "Field test, approach for Bradley laser system," Army Times, 9 October 1989, p. 36.

[3] William Fowler, "Lasers in the Field," Defence, November 1989, p. 868.

[4] "Imatronic's New Mini-Lasers Take Advantage of Solid State Technology," Defence, June 1989, p. 463.

[5] U.S. Army, CACDA The United States Army Tactical Directed Energy Warfare Master Plan, Volume I (Management Plan), October 1987, p. 1. This document, published by the Army's Proponent for Directed Energy Warfare, details management actions to develop and field laser weapons. Volumes II and III detail the technology and threat.

The difficulty in adjusting to lasers on the battlefield is understandable given the rapid introduction of laser technology into the military inventory. Theodore Maiman made the first laser in 1960, and by the late 1960s, laser rangefinders were already on tanks.[9,10] Lasers are now part of many military applications. Over 30,000 eye-hazardous lasers are in both U.S. and USSR active inventories.[11] Projectile guidance systems, rangefinders, and target designators use lasers. Lasers are also used in target tracking, training, navigation, submarine detection, communications, and as components in

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[6]M.R. Thurman, "Army Science Board 1988 Spring Meeting," Briefing, 22 March 1988. GEN Thurman asked the Board to review specific areas of DEW, including the proliferation of the technology, DEW's war-fighting contribution, future management structure changes, and implications for doctrine, training, and vulnerability.

[7]Dave Maddox, "Directed Energy Warfare Requirements," Briefing prepared for Industry Roundtable on Directed Energy, 28-29 September 1988. MG Maddox stated TRADOC's perspective on the Army's defensive capabilities, the types of lasers fielded, potential combat responses to being lased, approved laser protection requirements, and defensive laser issues.

[8]The Army Tactical DE Master Plan, p. 1-3.

[9]Jeff Hecht, Beam Weapons, The Next Arms Race (New York, Plenum Press, 1984), p. 25.

[10]Bengt Anderberg, "The Low-Energy Laser aimed at the eye as a potential Anti-Personnel Weapon," The Royal United Services Institute, Spring 1988, pp. 35-39.

[11]U.S. Army, TRADOC, "Unclassified Directed Energy Threat," Message, 8 November 1988, para. 1D. Message summarized Army Intelligence Agency Memorandum dated 30 Sept 88 (same subject) and DA DCSINT message (ATIS-TST, 261510Z Jan 87, Subject: Directed Energy Threat). The memorandum specifies which lasers are used by WARSAW Pact nations, how they will be employed, and how to react when targeted.

many other products.[12] Appendix C, details the laser development programs of the two countries; Appendix B summarizes the known injury mechanisms.

PURPOSE

The purpose of this thesis is to estimate the number of laser injuries likely to occur and to determine the impact on medical operations. The thesis question is, "What are the medical implications of lasers being used on the modern battlefield?"

To this end, this thesis delineates likely battlefield laser and troop dispositions. I needed to identify them and apply appropriate light propagation and injury models. I also needed to identify the relevant medical treatments and treatment location within the theater of operations. This thesis concludes with a list of shortfalls needing correction and my recommendations.

ASSUMPTIONS

The following six assumptions support this thesis:

(1) The tactical use of lasers will be that now stated in Army field manuals (FMs), teaching materials, military-produced and military-related magazines (Military Review, Infantry, Parameters, Air Force Review, Army Times, Air Force Times, Defense), and publications the Army Tactical DEW proponent publishes. The experts, usually in

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[12] Mike Witt, "Lasers in Military Roles," Asian Defence Journal, March 1988, pp. 4-16.

agreement, assume that existing USSR doctrine concerning deployment, maneuver, training, and organization is applicable to lasers. Field manuals and other training materials do not mention any offensive employment of lasers or laser weapons by the United States. I drew the tactical use, both offensive and defensive, from military-produced and military-related publications.

(2) Laser technology development, and the application of that technology to weapons, will continue. Despite the appearance of *glasnost* (openness) and *perestroika* (re-structuring) within the USSR, laser technology will continue to maintain a high priority for national resources for the USSR and NATO. Recent European reductions in quantity, matched with increases in quality, reinforce this belief.[13] This assumption is necessary to estimate the characteristics or fielding plans for laser weapons that are currently under development or that will be developed in the future.[14]

The next four assumptions are necessary to estimate the number of laser casualties:

(3) Soldiers will use target acquisition systems, designators, and rangefinders to harass or blind the enemy when advantageous.

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[13] Soviet Military Power: Prospects for Change 1989 (Washington, D.C.: Government Printing Office, 1989), p. 30-39.

[14] See Chapter 3.

(4) Soldiers directly opposing an enemy will look at him and become susceptible to eye injury from his laser. The rationale behind this assumption is that while the soldier may fear being blinded as he looks at the attacking tank or helicopter, he also knows that if he does not look, the enemy can maneuver at will and kill him with other weapons systems, such as guns and missiles.

(5) The Army will establish tactical procedures to minimize fratricide.

(6) The technical capabilities and specifications for current and future USSR systems will be similar to known U S. or WARSAW Pact nation's systems.

Other assumptions are not as obvious, and assumptions built into the TRADOC models are, of course, not re-stated. (This thesis uses the TRADOC Common Training Scenario and the computer supported TRADOC Tactical Commanders Development Course (using the National Training Center or the Joint Readiness Training Center terrain) simulation.) There are generally accepted medical assumptions that underlie the dose/effect mechanism to determine bioeffects. Finally, I have incorporated but not stated the assumptions made by the proponents of the laser light propagation models. The footnotes contain the source or rationale for the selection of the mathematical values used in the propagation models. Appendix D models some of the know WARSAW Pact nations and U.S. laser systems.[15]

DEFINITION OF TERMS

Terms of special importance to this thesis include the following:

Adjunctive laser. A larer which performs an ancillary function to make the killing mechanism of a weapons system (tank, helicopter, or bomb) work or be more effective. For example, the laser rangefinder uses a laser to assist the tank round hit the target but does not destroy the target itself.

Co-visibility. The line of sight and focus between the laser and the observer. Both are in sight of each other, although they may not be aware of each other.

Directed energy warfare. Using lasers, microwaves, or particle beams to illuminate, range, identify, jam, disrupt, damage, or destroy a target.[16] Because the technological requirements to develop these weapons are similar, they are grouped together.

Laser weapon. Any laser used to inflict physical injury or materiel destruction and includes adjunctive, commercial, or any other laser.

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[15]See Appendix D.

[16]The DEW Tactical Master Plan, p. 1.

Laser injury. Any effect on the soldier as a result of laser exposure or the threat of laser exposure requiring medical attention.

Low-energy laser (LEL). The currently fielded lasers used for ranging, illuminating, and designating targets. Low-energy lasers produce less than one joule of light.

High-energy laser (HEL). A much more powerful laser than an LEL. High-energy lasers may cause mechanical damage to aircraft canopies or produce eye injuries even 10 degrees off axis (roughly a 200-meter wide zone produced by a laser a kilometer away). High-energy lasers produce more than 100 joules of light energy.

A more complete listing of laser-related terms can be found in the Glossary, the U.S. Army Tactical Directed Energy Warfare Master Plan, and the U.S. Army Capstone Manual on Directed Energy.[17,18]

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[17] U.S. Army, CACDA The United States Army Tactical Directed Energy Warfare Master Plan, Volume I (Management Plan), October 1987.

[18] U.S. Army, CACDA U.S. Army Capstone Manual on Directed Energy, September 1983.

LIMITATIONS AND DELIMITATIONS

This thesis uses unclassified sources only, which broadens its audience and increases its utility. The bibliography and text references include classified sources helpful for the reader's continued research.

This thesis uses the CGSC's Tactical Commanders Development Course (TCDC) computer simulation to define unit deployment. This minimized researcher bias and maximized real-world tactics and provides a common frame of reference for future studies. However, access to the computer and the model is limited for student research.

Although the laser will be another source of stress on the battlefield, this thesis only considers eye injuries. Not only will lasers blind soldiers, their effects will produce stress casualties. Also, I have only considered U.S. casualties caused by the opposing force's use of laser weapons; this thesis does not measure the U.S.'s treatment of enemy wounded produced by lasers. I have also not attempted to demonstrate that the U.S. Army should develop or field laser weapons. I have considered all military lasers capable of producing injury, excluding lasers used for medical, communications, information storage, and any eye-safe military lasers such as the new carbon-dioxide laser rangefinder, projected for use in the Abrams tank. I have included as weapons lasers categorized as adjuncts. While an adjunctive laser's function is not to cause damage, it can.

SIGNIFICANCE OF STUDY

This study should determine if changes in medical staffing are necessary because of existing and future battlefield lasers, given their potential for causing injuries. As yet, the Army has not been done so. In 1987, the MRDC conducted a program in-progress review of the medically related directed energy warfare programs. The MRDC addressed the materiel protection problem, but not the potential impact of lasers on staffing, doctrine, training, and medical unit organizational structure.[19]

Because I exploited very little of the TCDC combat simulation's potential, during my research I wanted to find if a more detailed study was warranted.

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[19]U.S. Army, MRDC, DEW In-Process Review, 14 April 1987. In-Process Review Agenda was Laser energy bioeffects research, microwave/millimeter wave/particle beam research, DEW personnel protection development, aviation specific DE concerns, and funding issues and proposed strategies for milestone development.

CHAPTER 2

LITERATURE SURVEY

The survey defines the state of military laser technology and weaponization and examines the potential use of lasers as weapons, the bioeffects, and medical capacity to treat soldiers suffering laser injuries. I found battlefield laser information under the topical headings of directed energy weapons, beam weapons, and space weapons. Approved and in-draft laser-related tactical doctrine, U.S. assessments of the threat, and combat histories describe laser use. The most current bioeffects data are in medical center monographs and conference proceedings, laser safety publications, and combat psychiatry literature.

TECHNOLOGY AND WEAPONIZATION

These documents form the basis for Appendix C which describes current military laser technology and weaponization. My sources include textbooks, newspapers, periodicals, and technical journals. I also used Army briefings, studies, and Department of Defense, Joint Chiefs of Staff, Air Force, and Navy publications.

Jeff Hecht's Beam Weapons, The Next Arms Race is an excellent introduction to the subject of laser weapons.[1] Hecht tells the history, describes the technology, and discusses the military potential of beam weapons (lasers, high-power microwaves (HPM), and particle beams). He outlines likely systems and tactics based on the unique characteristics of lasers. Advanced Technology Warfare, edited by COL Richard Friedman et al., demonstrates the extent to which laser technology has been applied.[2] It also exemplifies how broadly lasers are integrated into the heavy forces of many nations.

The Defense Electronics summary of laser technology and weapon prototypes shows that laser weapons are now under development and soon could be fielded.[3,4] Supporting articles appear in Military Technology, and Defense.[5] Equipment advertisements show imbedded lasers. By cross-referencing this information with The Balance of Military Power World Defence Almanac and Jane's Armor and Artillery, one is able to estimate possible laser integration in Third World defense forces.[6,7] A measure

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[1]Jeff Hecht, Beam Weapons, The Next Arms Race (New York, NY, Plenum Press, 1984).

[2]Richard Friedman et al., Advanced Technology Warfare, (New York, Harmony Books, 1985).

[3]James W. Rawles, "Lasers: The Battlefield Tools of Tomorrow Are Here," Defense Electronics, July 1989.

[4]James W. Rawles, "Laser Weapons on the Battlefield," Defense Electronics, August 1989.

[5]See bibliography.

[6]Monch Media, Inc., Washington, D.C.

of the state of the art is also in Lasers & Optronics; the December "Buying Guide" yields product, safety, military specifications, and current information sources.[8]

The Combined Arms Combat Developments Activity (CACDA) published a DEW Master Plan and a DEW update summarizing the programmatic status of tactical laser systems.[9,10] It also published the status of studies and tests, threat information, and protection. Similarly, the Combined Arms Training Activity (CATA), Fort Leavenworth, Kansas, provided information about DEW awareness training.[11,12] These documents show that the Army places a high priority on awareness training, materiel protection for individuals and systems, and continued development of low-power laser systems.

The general threat posed by lasers is well documented. The Army's unclassified laser threat describes the significant number of rangefinders and designators in WARSAW Pact nations' active inventories. The report does

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[7] Jane's Armour and Artillery, 1987-88 (Tonbridge, Kent, Tonbridge Printers Ltd., 1988).

[8] Lasers & Optronics. Gordon Publications, Dover, NJ.

[9] U.S. Army, CACDA, The United States Army Tactical Directed Energy Warfare Master Plan, Volume I (Management Plan), October 1987. CACDA is the Army's proponent for tactical directed energy warfare (DEW).

[10] U.S. Army, CACDA, Message (132000Z Feb 89 from ATZL-CAG to multiple sources) "Directed Energy Warfare (DEW) Status Report," 13 February 1989.

[11] U.S. Army, CATA, Special Text 1-1, Directed Energy Warfare Awareness Training, 25 November 1987.

[12] U.S. Army, CATA, "Summary of DEW Training Status Report," Undated. On file at CACDA, ATZL-CAM.

not address laser weapons or laser use by Third World countries. However, it does state that an intent by some countries to use already deployed lasers against troops in battle.[13]

To perform the analysis in this thesis, I could only estimate the fielding and specifications of USSR and other WARSAW Pact nations laser rangefinders and designators. The USSR Future Soviet Tank (FST), T80, T72 (most versions), T62 (upgraded), T55 (upgraded) and T54 (upgraded) tanks have rangefinders.[14] No laser rangefinder is attributed to the USSR's armored personnel carriers, self-propelled field guns and howitzers, and self-propelled antiaircraft guns and reconnaissance vehicles.

The USSR artillery uses both tripod- (the DAK-1) and vehicle-mounted laser rangefinders; no technical specifications were provided.[15] However, much of the equipment used by the Chinese is based on early USSR designs and technical specifications for the Chinese systems.[16,17] USSR improvements in rangefinder optics

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[13]U.S. Army, TRADOC, Message, "Unclassified Directed Energy Threat," 8 November 1988.

[14]Jane's Armour and Artillery 1988-89, p. 68-78. An examination of tanks from other countries reveals that a laser rangefinder is a common component of modern tanks. The Chinese T80, T79, T69, and T59 use them as do French, Swedish, United Kingdom, German, U.S., and Korean tanks.

[15]Jane's Weapon Systems 1986-89, (Tonbridge, Kent, Tonbridge Printers Ltd., 1988.), p. 379.

[16]Ibid., p. 349.

over early systems, however, makes Chinese specifications no more than an indication of USSR capabilities today.[18] Table 1 shows the doctrinal disposition of USSR rangefinders.[19]

BIOEFFECTS

The following sources are the basis for Appendix B. The Letterman Army Institute of Research (LAIR) monographs and conference proceedings summarize the Tri-Service laser threat and the weapon and protection programs.[20,21]

In May 1989, the Health Physics Society published a special issue of Health Physics.[22] The text, titled "The Proceedings of the First Symposium on the Biological Effects, Hazards and Protection From Non-Ionizing

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[17] Xu Jiemin, et al., "Experimental Studies of the Injurious effects of Q-switched Nd:YAG Lasers and Their Outdoor Applications," Health Physics Journal, May 1989, p. 647-652. Lasers of 120, 100 and 10 mJ with a beam divergence of about 1, 2 and 1 mrad, respectively.

[18] Personal communication from CACDA (ATZL-CAG). Without USSR improvements, the many multiple service laser protection programs make no sense. See Appendix D.

[19] U.S. Army, FM 100-2-3 The Soviet Army: Troops, Organization and Equipment, July 1984, p. 4-39, 4-49, and 4-105.

[20] U.S. Army, LAIR, Combat Ocular Problems, Proceedings of Conference, October 1980. LAIR is the Army's primary medical laser research facility. LAIR sponsors the international conference, Lasers on the Modern Battlefield, each October. Proceedings (classified SECRET) are published. The School of Aerospace Medicine (Brooks AFB, San Antonio, Tex.) is the Air Force's medical laser-research facility.

[21] U.S. Army, LAIR, Combat Ocular Problems, April 1982.

[22] David Sliney et al., Health Physics "Special Issue of The Health Physics Journal, Proceedings of the First Symposium on the Biological Effects, Hazards and Protection From Non-Ionizing Radiation in Outdoor Applications," (New York, Pergamon Press, May 1989): pp. 603-802.

Table 1

Disposition of Fielded Lasers

Unit	Number	Equipment or Unit
Tank Division (TD)	368	328 Tanks and 40 rangefinders 5 (x3) Tank Regiment 8 MRR (BMP), 15 Arty regiments 2 Arty command batteries
Motorized Rifle Division (MRD)	268	220 Tanks and 48 rangefinders 24 in MRRs (8/BTR (x2), 8/BMP) 15 in Arty regiment 3 in antitank bn 2 in arty command batteries
Tank Regiment (TR)	99	94 Tanks and 4 SP howitzer bn 1 in MRB (BMP)
Motorized Rifle Regiment (MRR)	48	40 Tanks, 1 (x3) in MRB 4 in howitzer bn, 1 in antitank missile battery
Independent Tank Battalion (ITB)	41	41 Tanks
Motorized Rifle Battalion (MRB)	1	1 in mortar battery
AntiTank Battalion	3	3 in antitank gun battery
SP Howitzer Battalion	4	(not specified)
Artillery Regiment	15	1 in HQ, 4 (x2) howitzer bn 4 in SP howitzer bn 2 in target acquisition bn
Artillery Battalion	4	1 (x3) mortar battery 1 (not specified)

Radiation in Outdoor Applications," is comprehensive, timely, and directly applicable to this study. Topics include bioeffects on the eyes and skin, laser accident experiences, and a detailed discussion of the vulnerability of the eye to injuries from military rangefinders.

The Laser and Optical Hazards Course Manual, produced by the Army Environmental Hygiene Agency, provides a thorough discussion of bioeffects and laser light propagation.[23] It also includes an extensive bibliography (over 2,400 references) and technical details to evaluate military laser hazards.

Although not included in the casualty calculations, the causes, treatment, and impact of stress are covered in Richard A. Gabriel's Soviet Military Psychiatry and Military Psychiatry.[24,25] Blindness is mentioned as a potential stress reaction. Gregory Belenky, in Contemporary Studies in Combat Psychiatry, discusses future treatment requirements.[26] He shows that the impact of battle intensity and the soldier's reduced ability to control his environment increases the number of stress casualties.

DOCTRINE

Medical

The HSC is staffing a draft of FM-8-50, Prevention and Medical Management of Laser Injuries (in draft for

[23]U.S. Army, AEHA, Laser and Optical Hazards Course Manual, January 1982.

[24]Richard A. Gabriel, Soviet Military Psychiatry, The Theory and Practice of Coping With Battle Stress (New York, Greenwood Press, 1986). Gabriel states the Soviets witnessed blindness as a severe conversion reaction.

[25]Richard A. Gabriel, et al., Military Psychiatry, A Comparative Perspective (New York, Greenwood Press, 1986).

[26]Gregory Belenky, et al., Contemporary Studies in Combat Psychiatry (New York, Greenwood Press, 1987).

over three years).[27] It briefly outlines laser treatment. Other medical FMs refer to DEW and lasers in general terms only. FM 8-55, Planning for Health Service Support, provides no quantitative guidance.[28] The HSC set a Wounded In Action (WIA) Code for directed energy eye lesions, sets laser injuries at one percent of the WIA, and establishes evacuation rates.[29] The most recent draft of Health Services Support Futures, HSC's plan to support the Army's AirLand Battle concept, mentions lasers in passing.[30]

The Army has not conducted a quantitative study to estimate casualties or examine medical implications.[31] The approved Army models are system (vehicle) oriented and provide limited information about injuries to individual soldiers.[32]

NonMedical

A DEW Appendix is now part of FM 71-1, Tank and Mechanized Infantry Company Team, FM 71-2, The Tank and

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[27]U.S. Army, Academy of Health Sciences, Fort Sam Houston, TX, FM 8-50 Prevention and Medical Management of Laser Injuries (Coordinating Draft), July 1989.

[28]U.S. Army, FM 8-55, Planning for Health Service Support, February, 1985.

[29]U.S. Army, HSC, WIA Distribution After Panel 880427, July 1987. Computer report issued by the HSC.

[30]U.S. Army, AHS, Health Service Support Futures, March 1989.

[31]Information provided by CACDA, TRADOC Program Integration Office (TPIO) - Technology Exploitation, Army Tactical DEW Proponent.

[32]Information provided by CACDA, TRADOC Program Integration Office (TPIO) - Technology Exploitation Office, Army Tactical DEW Proponent.

Mechanized Infantry Battalion Task Force, and FM 71-100, Division Operations.[33,34,35] These FMs tell the soldier to expect to be lased. The doctrine directs commanders to plan for DEW, report its use, increase protection levels, suppress the enemy with conventional fires, employ obscurants, and continue the mission. Soldiers who look at the battle, particularly through optics, are identified as being at greatest risk.

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[33] U.S. Army, FM 71-1, Tank and Mechanized Infantry Company Team, November 1988.

[34] U.S. Army, FM 71-2, The Tank and Mechanized Infantry Battalion Task Force, September 1988.

[35] U.S. Army, FM 71-100, Division Operations, November 1988.

CHAPTER 3

METHODS AND PROCEDURES

This chapter specifies the way for determining the number of laser injuries and details their impact on medical operations. The thesis model I used is not completely new; rather, it combines preexisting models.

THESIS MODEL

The model assesses scenarios which depict potential battalion casualties as part of a high-intensity conflict (HIC), a mid-intensity conflict (MIC), and a low-intensity conflict (LIC). In the HIC scenario, a heavy U.S. force is opposed by a heavy Soviet-like force. In the MIC scenario, a light infantry battalion is augmented with armor and will be, again, opposed by heavy units. In the LIC scenario, I used a light infantry battalion for both antagonists.

The model also assesses three different laser systems:

o Lasers already fielded (adjuncts, the armor and artillery rangefinders and designators).

o Laser weapons systems known to exist (under development) but not yet fielded.

o A future system (arbitrarily defined as replacing the currently fielded laser systems one-for-one capable of locating and attacking optics with 10 times more power than the postulated near-term systems.

The model proposes a Stingray-like system placed on tanks to model a short-term laser weapon.[1] The model also supplies a hand-held laser rifle supplied to each nonmechanized opposition force (OPFOR) company.[2] My literature search did not reveal a basis of issue for laser weapons; the distribution I used here takes a conservative approach which reflects that often attributed to the WARSAW Pact nations; uses proven designs, focuses on high-value elements, and keeps control of new systems.

After defining laser hazards, the next step was to define the battlefield. The following elements must be identified and varied with the battle: terrain, unit size and location, laser equipment locations, equipment characteristics, tactics, mission, weather and visibility, and supporting units. These features are all part of the computer simulation supporting the CGSC Tactical Commanders Development Course (TCDC), Fort Leavenworth, Kansas. Appendices E, F, and G contain engagement data. The

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[1]See Appendix C for a description of the U.S. Stingray system. Also see footnotes 66 and 67 and related text in this chapter which states that such a system is also integrated into the USSR force structure.

[2]An equally likely distribution for laser weapons would be to limit them to special units only.

simulation uses National Training Center (NTC) or Joint Readiness Training Center (JRTC) terrain with U.S. units played against an interactive USSR-like force (the OPFOR). I obtained snapshots of the TCDC model's battle showing locations of U.S. forces as well as the OPFOR (equipment using lasers). The sceneros represent likely conflicts.

I also needed to predict the effects lasers on soldiers' eyes. I choose to use the Lawrence Livermore National Laboratory Laser (LLNL) Air Defense Model, because it is robust and yields a useful result for this thesis.[3] The model is judged robust because it considers the eye (pupil) collection area, scene luminance variation (allows for protective filters, obscurants, and weather effects), optics magnification, angular dependence, and laser energy. The model translates laser luminous energy (how much light gets to (or into) the eye per unit time) into treatment groups. Another reason I used the LLNL model is because it was the one CACDA (Army DEW proponent) suggested.

I also needed estimate the casualties. The LLNL model predicts a permanent blinding injury if 15 micro-Joules (uJ) of the laser's light strikes the macula of the eye. Consistent with the Army's approved threat, the lasing equipment in the model was used aggressively by the OPFOR. That is, the tank's rangefinder was used not only

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[3]Walter Sooy, Paper, "Lasers As Air Defense Weapons" presented at the Lasers on the Modern Battlefield Conference, January 1990.

to find the range but to deliberately try to cause a casualty.

I computed the model for the laser luminous energy for a variety of potential lasers, defining the injury zones (See Appendix D). I then examined the injury zones for vulnerable U.S. forces and tabulate the casualties. Factors I considered included the following:

o The use of optics. Soldiers using optics without the correct laser protection, are much more likely to be injured. (See Appendix D.)

o The orientation of the units. Are they looking at each other? Are dismounted troops near a tank being ranged?

o The terrain. Laser light travels only in a straight line.

o The range.

o The activity. A tank moving to another defensive position is not likely to be looking at the enemy at that moment.

I described factors and specifications of each laser and environment individually. For any classified specifications, I presented a rationale for the values I selected.[4,5] I intend to summarize the casualty figures produced by each laser category in the conflicts. The mission, forces, tactics, medical support, and other associated factors during the battlefield engagement are constant for each class of laser modeled.

The result will be a histogram showing the number of soldiers injured versus the type of injury and compared with the capability of medical support provided to the battalion (as defined by the TCDC model and doctrine). Patient treatment needs, based on injury incurred, will be compared with the location of the treatment capability. Finally, I intend to identify shortfalls and make recommendations.

PROCEDURE

I followed these steps to obtain the raw casualty data. As part of the actual TCDC classroom exercise, each scenario was recorded, replayed, and a hard copy of the screen (showing the unit's disposition) obtained at regular

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[4]The Stingray's output and divergence is estimated to be 24 Joules (J) and 0.08 mrad, respectively. This estimate is based on a system designed to negate (deliver 15 uJ of energy from a Nd:YAG laser) the gunner of a T64, T72, or T80 tank. The sighting range is 4,000 meters or less for HEAT, HE 11, and APFSDS tank rounds using the 7x TSh2B-41 telescope. The specifications and uses of the TSh2B-41 gunner's telescope are in Jane's 1988 Armour and Artillery, p. 77.

[5]The power and divergence for the hand-held laser rifle was estimated to be 10 Joules and 0.1 mrad. A smaller system probably would be of limited tactical use. The postulated system would project 15 uJ of light at 600 meters, according to the LLNL model.

intervals (every 10 or 20 minutes.) I then identified and numbered the elements of the U.S. and OPFOR units. I determined the line of sight and element activity by through discussions with the simulation controllers and by studying the hard copy outputs as a series. I identified the locations of potential OPFOR lasers were identified (in turn, the current systems, near-term deployable systems, and projected future weapons.)

I then measured the range between each of the U.S. elements and the laser having co-visibility within each time segment.* I then tracked each U.S. unit to see if it was later destroyed by conventional fires. I then compared the range between units with the damage range calculated by the LLNL model. The estimated number and type of casualties were then to be determined.

METHODOLOGY STRENGTHS AND WEAKNESSES

The TCDC model is both a source of strength and weakness. Because only battalions (with limited aviation) can be played, the density of laser systems proved low and the medical support limited to the unit level. I studied only three battalion encounters. This limited the applicability of my recommendations. But, because many Army leaders have used the same battle scenarios and terrain, they can better evaluate my findings and

*In fact, I considered two ranges--the range where covisibility occurred and the closest range between the laser and the potential victim.

recommendations. The TCDC model was not designed to consider laser effects. However, the findings prove the model can show future laser effects and the need to include them in future planning.

A strong point of the model is that it lends itself to real-life scenarios. The short battles scenarios are applicable in the Middle East, Central America, or elsewhere. Although pitting light units against light units is a historic deployment in mountainous and heavily forested terrains, future conflict between light forces may become the norm in any terrain when nations try to rapidly deploy forces.

In the LIC scenario, the U.S. has air superiority, limited medical support on the ground, and long and extended lines of communication for evacuation (if Panama and Grenada are representative of future conflicts). In the MIC scenario, a light U.S. battalion augmented with limited mechanized support, is opposed by a well-equipped and trained Soviet-like force. (A possibility in many parts of the world! For example, U.S. units may be used to quickly support a United Nation's peacekeeping effort and be opposed by heavy forces.) In the model, OPFOR air defense denies total U.S. air superiority. Medical support was limited to transporting patients by ground to the rear.

An inability to estimate the technical specifications necessary to perform laser beam propagation calculations is a weakness in this study. There is very little unclassified literature concerning foreign laser-systems specifications and deployment; most technical specifications are classified. Unofficial estimates were drawn from Jane's and other defense-related publications. Other weaknesses in the study are in assuming weapons densities and in forming a system-specific definition for future laser systems. The strength of the study is its straightforward approach. It postulates the number of casualties, determines the actual level of medical care available, and examines the impact of the lasers in terms of intensity of conflict and characteristics of laser systems.

LASER SYSTEMS AND THEIR EFFECTS

Appendix C describes currently fielded lasers. Table 1[7] shows the location of lasers in actual Soviet units. Appendix D shows the amount of light entering the eye at various distances for the tank rangefinders for the United States, Nationalist China, and a number of notional systems.

The LLNL model predicts that the M1 rangefinder could blind soldiers as far away as 260 meters on a clear

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[7]See p. 15.

day.[8] If the beam striking the eye is degraded to one one-hundredth (1/100) of its maximum because of smoke, fog, or viewing the laser at an angle instead of directly; the blinding range would be only 30 meters. A Chinese rangefinder could blind soldiers up to 60 meters away, but the expected battlefield-degraded beam will only cause an injury at a distance less than 10 meters. If, however, the same degraded beam were viewed by a soldier using 7x binoculars, the laser is predicted to be able to cause an injury out to 50 meters.

The laser rangefinder attributed to the OPFOR in this thesis has an output of 120 milli-Joules (120 mJ, or 0.12 Joules) and one-tenth (0.1) mrad divergence. These specifications were based on the review of literature.[9] Other likely specifications would have led to the same findings and recommendations.

The modeled OPFOR laser had a blinding range of 70 meters on the obscured battlefield, 200 meters if viewed with 3x binoculars, and 450 meters for 7x binoculars.

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[8]See Appendix D. The LLNL model postulates a Wolfe Grade II (WG II) eye injury grading system; (See Appendix B) response to the fovea at 15 uJ and WG III at 30 uJ. A soldier with a WGII injury would see a flash followed by partial recovery of vision in a few weeks. A soldier with a WG III (retinal hemorrhage) would see a cloud of red. The soldier would recovery his vision slowly ending in 20/100 to 20/400 vision. The soldier may still be able to perform gross visual tasks.

[9]See Chapter 2, footnotes 14-18. I modeled a laser roughly three times more powerful than the M1, but with poorer optics.

American soldiers using the newly fielded 50-mm binoculars could be able to look at the OPFOR laser as close as 60 meters, because laser protection has been built in. Laser protection is also being incorporated into other Army optical systems.[10]

I modeled the OPFOR near-term laser system with a capability generally attributed to U.S. and USSR vehicle and infantry-carried systems (as described in Appendix C). I modeled the OPFOR infantry laser rifle to cause an injury to another infantry soldier 600 meters away and to a tank gunner up to 2,600 meters away.

The OPFOR future laser system was modeled as replacing all the currently fielded lasers and having 10 times the power of the postulated near-term systems. These weapons would be able to permanently injure infantry soldiers from between 1,500 meters (using a 100-J laser) to 2,000 meters (for a 240-J laser) away in the degraded battlefield environment. Using 7x optics extends the injury zone to over 5,000 meters. Using minimal (reducing light to 1/100) laser protection reduces these very powerful systems' ability to injure soldiers from 200 to 300 meters or 1,100 to 1,600 meters away for optical (7x) equipment users.

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[10]The Army is currently fielding binoculars with laser protection. They protect the soldier against the most common lasers (ruby and Nd:YAG). The laser-protected binoculars can be identified by their greenish reflective surface on the front.

MEDICAL DOCTRINE RELATED TO LASERS

FM 8-50, Prevention and Medical Management of Laser Injuries (Coordinating Draft) provides a general description of laser hazards and the enormous potential for psychological effects.[11] There is a very simple chart in FM 8-50 listing the signs, symptoms, diagnosis, and treatments; there is a also an evaluation flowchart for aidman. However, the manual lacks: the distances at which flashblinding, eye damage, or permanent blinding are likely or possible from either U.S. or foreign systems, the expected number and types of patients, and the expected returns-to-duty rate.[12]

FM 8-55, Planning for Health Service Support, provides no quantitative guidance for laser injuries.[13] It states that too many uncertainties now exist to be able to establish planning factors. However, HSC has created a wounded-in-action (WIA) code for directed energy eye lesions (set at one percent of the WIA).[14] This action

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[11]U.S. Army, Academy of Health Sciences, Fort Sam Houston, TX, FM 8-50 Prevention and Medical Management of Laser Injuries (Coordinating Draft), July 1989.

[12]Nontactic occupational hazard distances are published in medical technical bulletins. See TB Med 506, Occupational and Environmental Health: Occupational Health and TB Med 524, Occupational and Environmental Health: Control of Hazards to Health from Laser Radiation.

[13]U.S. Army, FM 8-55, Planning for Health Service Support, February 1985, para. 3-7.

[14]U.S. Army, HSC, Computer report, WIA Distribution After Panel 890427, July 1987.

prepares the Army Medical Department (AMEDD) to be able to count future laser injuries.

While little approved tactical medical doctrine concerning lasers exists, the AMEDD has excellent laser safety and biomedical research programs. And, of course, AMEDD publications and medical training programs address the general treatment of eye injuries and combat stress casualties.

MEDICAL ASSETS AND CAPABILITIES

Health service support is provided within the theater of operations at the unit (battalion), divisional, corps, corps support, and communications zone levels. At the unit level, aidmen are normally allocated to infantry battalions on the basis of one aidman per rifle platoon plus an additional aidman per rifle company. The aidman provides emergency medical care, returns to duty soldiers not requiring further care, directs ambulatory patients (those able to transport themselves) to the company aid post or battalion aid station, arranges for evacuation of litter patients, and initiates field medical cards.[15] The company aid station provides additional care for patients requiring further evacuation, treats minor wounds, returns soldiers to duty, verifies information on field medical cards, and prepares for the evacuation of the

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[15] U.S. Army, FM 8-15, Medical Support in Divisions, Separate Brigades, and the Armored Cavalry Regiment, September 1972, p. 2-4.

patients. The company aid station does not provide shelter or mess capability.[16]

Division-level medical support consists of a medical battalion which normally places a medical company (to operate a division clearing station) in support of each combat brigade. The division-level medical support units reinforce unit-level medical support and provide ambulance evacuation from the unit medical elements and consultation services (dermatology, orthopedics, psychiatric/social services, and aviation medicine). Division-level medical support units have a very limited short-term holding capability.[17]

At Corps and Theater levels, a variety of hospitals exists which provide resuscitative and definitive treatment. This level is where ophthalmology medical detachments have historically been assigned as part of either the Medical Group (Theater level) or the Medical Brigade (Corps level).[18,19]

FM 8-50 (Draft) states, "There is, as of yet, no definitive treatment for a laser injury to the eye. The treatment of corneal burns is the same as for (other)

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[16] Ibid., p. 2-5.

[17] Ibid., p. 2-17 through 2-20.

[18] The Surgical Service Team, TOE 08-63C (KH), consists of two physicians. The basis of allocation is as required.

[19] U.S. Army, FM 8-10 Health Service Support In A Theater Of Operations, October 1978, p. 1-7 through 1-10, and C-4.

burns."[20] This grim appraisal is stated in nonmilitary medical journals as well.[21] FM 8-230, Medical Specialist, quickly covers the treatment of laser eye injuries, "Immediate first aid is usually not required, bandaging the eye may make the patient more comfortable and protect his eyes from further injury and from further exposure."[22] (FM 8-50 directs that no patch be used.)[23]

Only FM 8-50 (Draft) addresses the important return-to-duty issue. In short, it states that if there is no pain and the soldier can see, he can return to duty. If not, the soldier is to be evacuated to the battalion aid station where he will be treated by a physician or physician's assistant. How to process soldiers who can still see from one eye is not discussed in medical or tactical field manuals.

COMPARISON OF REQUIREMENTS AND RESOURCES

The medical requirements to treat laser injuries are low. At the aid station, there is no first aid required for a laser eye injury beyond triage and controlling stress. As stated above, little can be done at the Division-level either. FM 8-50 (Draft) highlights the need for triage, evacuation, and control and treatment of

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[20] FM 8-50 (Draft), p. 20.

[21] See Appendix B, footnote 17.

[22] U.S. Army, Medical Specialist, FM 8-230, August 1984, p. 13-140.

[23] FM 8-50, p. 26.

battle fatigue (combat stress). Medical units do not need to evacuate patients quickly (for medical reasons, as opposed to tactical or logistical requirements), because the patient's condition will not deteriorate. Health Service Support Futures makes many references to battle fatigue indicating that the AMEDD is already restructuring to treat the increased numbers of combat fatigue casualties based on non-laser battlefield requirements.[34]
Therefore, there appears to be adequate medical care resources to address the addition of lasers on the battlefield, since only limited medical care need be provided.

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[34]U.S. Army, AHS, Health Service Support Futures, March 1989.

CHAPTER 4

ANALYSIS AND FINDINGS

The thesis model and the definition of both the battlefield and lasers proved too coarse to calculate the resulting casualties. However, significant findings were evident, including--

(1) Lasers on the battlefield (with the resulting evacuation of the injured) are more command and training issues than medical.

(2) Current medical staffing and organization are adequate.

The model definition of the battle did not provide enough detail because--

o Often too much activity occurred between the snapshots. Military elements disappeared without it being clear whether the unit was killed or had withdrawn.

o Identification of specific elements was impossible during periods of rapid movement.

o The model required too many rules to decide whether or not a laser casualty occurred, and many of the casualties resulted from arbitrary decisions.

o Too often, small changes in maneuver greatly reduced, or increased, the number of injured.

The uncertainty in the characteristics of the laser weapons also proved to be too broad to confidently bound the future number of injured soldiers. The zone in which a laser could cause an injury varied greatly with the technical parameters of the laser, the acquisition and targeting subsystems, and the laser's physical location within the military unit. Dramatic reductions in casualties followed the introduction of simple tactical and materiel protective measures. On the other hand, ignoring the possibility of laser injury (not using laser-protection materials or protective tactical techniques) greatly increased the casualty rates.

Other factors which introduced great uncertainty were laser-produced glare and temporary flashblindness. If a soldier was temporarily unable to see, he might not be permanently blinded no matter how close or well aimed the enemy's laser was because the soldier would no longer be looking at the battlefield. Thus, the specific casualty figures, which the thesis originally attempted to quantify, were of limited and questionable value.

Two simple cases, however, repeated themselves within all scenarios. Either the laser system was very effective (producing a large number of casualties) or very ineffective. An ineffective laser weapon produces few casualties, has little impact on medical units, and need not be considered in depth. But, the impact an effective laser weapon is counterintuitive and worthy of greater study, because where the lasers were very effective, a large number of injuries resulted.

An effective blinder will, it is predicted, also drastically increase combat fatigue, producing stress casualties with no eye injury at all. Some soldiers will only be blinded in one eye; some in both. Other soldiers will have just their fine (central or reading) vision degraded. Still others will only be temporarily flashblinded and can quickly return to the unit.

Since there is no first aid or resusciatative treatment, unit- and division-level medical units can only return soldiers to duty, hold them, or evacuate them. The need to evacuate was first thought to be so great it would overwhelm the medical capability, but this will most likely not happen, because--

(1) In most real-life scenarios, replacements will be not be available to the tactical commander, and he will take the necessary action to get these soldiers back on line.

(2) The patients are medically stable, and they can be evacuated or returned to limited duty at whatever level necessary based on logistical and tactical rather than medical considerations.

(3) Since the patients can be provided no more medical care, and since unit- and division-level medical units have limited holding capability, the injured can only get support from that normally provided by the tactical commander; that is, food, housing, and clothing.

(4) Medical and tactical commanders can use the large number of partially blinded patients to care for the more uncommon totally blind patients.

(5) The commander will not be able to sustain his operations unless he controls the number of battle fatigue casualties and emphasizes nonmedical, command-directed programs to reduce them.

(6) The tactical commander will quickly discover the eye injuries are concentrated in a small number of critical-skill categories (the soldiers who target weapons systems or otherwise look at the battle), and because he must have them back to accomplish his mission, unless they are completely blinded, he cannot allow them to be evacuated. Protection of the laser casualty may be more of a tactical than medical issue; if the laser causes a large number of soldiers who are flashblinded (just cannot see for a few hours or days), they remain a significant portion of the tactical commander's fighting force, but one that he must now protect in order to use again.

With effective laser weapons, commanders will recognize the effectiveness of protective countermeasures and will implement awareness and training programs and increase his protective posture. The impact on the medical unit will be sharply reduced, and there will be an increased requirement to provide laser-injury awareness training.

Laser and poison gas weapons have many similar characteristics. Both are most effective against untrained or unprotected troops. Environmental factors modify their effectiveness and employment. Countermeasure can be effective, but countermeasures require an operational decrement. In the case of lasers, some level of vision must be given up. In both, only limited medical care is possible. The most effective medical contribution in both cases is probably to develop effective prevention and to educate commanders. In the case of laser-caused eye injury, there is the possibility of a new sight-restoring operation or an artificial eye being developed--both unlikely prospects.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The purpose of this thesis was to estimate the number of casualties and to determine the impact on medical operations from the proliferation of lasers on the battlefield, taking a quick look at lasers across the spectrum of conflict as they exist today and as they may develop in the future. During my research I made the following observations:

o Today's fielded lasers, adjunctive rangefinders, and designators will probably produce few injuries, unless the soldiers use binoculars or other optics without laser protection. The model generated low casualties because of the laser's relatively low power and narrow beam and because of the battlefield's geometry and obscurants.

o Laser weapons that can be fielded in the near future could be effective casualty producers against unprotected soldiers, even against dismounted infantry 200 meters away. Laser protection, if worn, sharply reduces the range of the laser weapons; that is, a laser weapon that could cause on injury 600 meters away must then be within 50 meters to cause the same injury. Future systems are predicted to have a devastating psychiatric impact unless protection keeps pace with laser weapons technology. Planners must consider means for indirect viewing of the battlefield if adequate protection is not developed and fielded.

o Health services organization and resources on the battlefield adequately address the additional workload expected from laser casualties. This study supports the need for the AMEDD to aggressively develop laser protection and to educate the Army at large about the potential threat to soldiers from lasers.

o A review of doctrinal literature revealed that laser-related doctrine is limited. It follows that laser impact awareness is also limited.

o Present and future lasers on the battlefield are more command and training issues than medical.

o Current medical staffing and organization are adequate.

RECOMMENDATIONS

Because of my conclusions, I--

(1) Recommend that the AMEDD add to the proposed FM 8-50--

o Distances where flashblinding and permanent blinding is likely, both for U.S. and foreign systems currently fielded, as well as those projected to be encountered. I strongly believe the American soldier has a right to information necessary for his own self-defense.

o The expected number and types of patients and the expected return to duties as a percent of total laser injuries.[1,2]

(2) Recommend that the AMEDD develop medical planning factors for laser injuries and include them in FM 101-10-1 and FM 8-55, because lasers exist on the battlefield and planning factors are required for accurate health care planning.[3,4] A cost-effective method to obtain the necessary battle casualty rates may be to establish a contract to incorporate (automate) the methodology in this thesis. With each TCDC cycle, the Army could gain a better estimate of laser casualties. Further, a comparative study of successful battles (with minimized laser injuries) would allow the Army to develop successful tactics for the laser battlefield. Such a contract should exploit the simulation's ability to see the battlefield from different perspectives and more carefully determine

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[1]U.S. Army, AHS, FM 8-50 Prevention and Medical Management of Laser Injuries (Coordinating Draft), July 1989.

[2]The Army Materiel Systems Analysis Activity published some of this information in its Laser Survivability Manual (U) Vol II: Leader's Guide, Technical Report No. 432. Unfortunately, this publication is classified SECRET/NO FOREIGN and has had limited distribution.

[3]U.S. Army, AHS, FM 101-10-1 Staff Officers' Field Manual: Organizational, Technical, and Logistical Data Planning Factors, October 1987.

[4]U.S. Army, FM 8-55, Planning for Health Services Support, February 1985.

the opportunity for laser injury. The effects of terrain, obscurants, movements, and measurement of engagement angles could then be more accurately determined.[5]

(3) Recommend that FM 8-50 (Draft) be approved immediately.[6] Although I believe the draft FM could be improved, I also believe its value is such that it should be distributed immediately.

(4) Recommend this study be repeated considering U.S. deployment of laser weapons to determine expected enemy casualties and to assess the U.S. medical system's ability to care for injured prisoners of war. (In this thesis, only the OPFOR had laser weapons, because only U.S. casualty rates were being studied.)

(5) Recommend the study be repeated using brigade and higher units. (This study was limited to battalion-size U.S. units.)

(6) Recommend that the AMEDD and the Army Materiel Command re-address the need to field protection for agile lasers (lasers which operate at a frequency determined by the user) and for lasers operating on nontraditional

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[5]My access to the computer and the model was limited to that which could be provided at no cost and which did not interfere with the normal classwork. I had limited access to classroom materials, the Blue and OPFOR controllers and instructors, and was provided hard copy "snapshots" of the battle taken at predetermined intervals.

[6]U.S. Army, AHS, FM 8-50, Prevention and Medical Management of Laser Injuries (Coordination Draft), June 1986.

frequencies. Specifically, I recommend the Army field neutral-density filters (OD 2 and OD 4) as part of the Ballistic-Laser Protective Spectacle package.

(7) Recommend that CATA increase its laser-awareness training program. As stated above, little laser doctrine exists, and the impact of lasers is rarely considered in planning. Laser-injury prevention can best be accomplished through individual soldier awareness and protection, and greater awareness training is definitely necessary. I also believe that impact of lasers on training requires greater study.

(8) Recommend that CATA and HSC study the command, training, and medical issues of laser-patient evacuation and return to duty. Aside from the observations made in Chapter 4, a retraining program within the theater of operations may be required for soldiers with laser-caused degraded vision.

GLOSSARY

AEHA	Army Environmental Hygiene Agency
AHS	Academy of Healthcare Sciences
AMEDD	Army Medical Department
CAC	Combined Arms Center
CACDA	Combined Arms Combat Developments Activity
CATA	Combined Army Training Activity
CGSC	Command and General Staff College
DE	directed energy
DEW	Directed-energy warfare
Flashblind	temporary loss of vision
FLIR	forward-looking infrared
HEL	High-energy laser
HIC	high-intensity conflict
HSC	Health Services Command
Hz	Hertz
J	Joule (unit of power, Watt/second)
LABCOM	Laboratory Command
LAIR	Letterman Army Institute of Research
LASER	Light amplification by stimulated emission of radiation
LEL	low-energy laser
LIC	low-intensity conflict
LLNL	Lawrence Livermore National Laboratory

LLTV	Low-light television
MIC	mid-intensity conflict
mJ	milliJoule
mm	millimeter
mrad	milliradian (angular measure)
mW	milliWatt
MRB	motorized rifle battalion (Soviet)
MRD	motorized rifle division (Soviet)
MRDC	Medical Research and Development Command
MRR	motorized rifle regiment (Soviet)
nsec	nanosecond
NATO	North Atlantic Treat Organization
Nd:YAG	neodymium-doped-yttrium-aluminum-garnet
NTC	National Training Center
OPFOR	opposition force
PGM	Precision-guided munitions
TB	Technical Bulletin
TCDC	Tactical Commanders Development Course
TD	tank division (Soviet)
TIE	total interocular energy
TOW	tube-launched, optically tracked, wire-guided missile
TPIO	TRADOC Program Integration Office
TRADOC	Training and Doctrine Command
SDI	Space Defense Initiative

SP	self-propelled
specs	specifications
uJ	microJoule (See J, above.)
Vis rg	visible range
W	Watt
WIA	wounded in action
WG	Wolfe Grade (category of laser eye injury)

APPENDIX A

AN INTRODUCTION TO LASERS

The battlefield effect of lasers, not the specific characteristics of lasers, is of primary concern. However, for completeness, I have provided a brief description of a laser and its characteristics. A laser converts electrical or chemical energy into a controlled beam of light. The natural oscillations between the energy levels of atoms or molecules are used to generate the laser's light which results in coherent electromagnetic radiation. (The word laser comes from the acronym, "Light Amplification by Stimulated Emission of Radiation"). The laser can use a crystal, a liquid, or a gas to store and convert the energy. The radiating light can be ultraviolet, visible, or infrared.

A typical ruby rangefinder works as follows. Light from a flashlamp excites the atoms in a specially prepared ruby rod. Electrons within the rod are trapped in an excited state. When there are more atoms in an excited state than in the normal state, the spontaneous decay of a few electrons create a chain reaction whech then intensifies the light. Mirrors on both ends of the rod reflect the light back into the chamber. The light continues to bounce back and forth exciting even more atoms. To return to their normal state the newly excited atoms soon release more light (traveling in the same direction as the light that orginally hit the atom). As the light bounces back and forth, more and more atoms are excited and more and more light is produced. All the light is in the same phase - all going the same direction. Eventually, the light "pushes" through one of the mirrors (which is intentionally less reflective than the other) creating a beam of light. (A switch inside the laser can start and stop the process.) The resultant laser light is very different from that normally encountered in nature. It is monochromatic; that is, it is all the same color or frequency. Light from the sun or a light bulb, on the other hand, is made up of light of many frequencies.

Another difference between the laser's output and normal light is the concentration or intensity of light. Although military field lasers usually have low power (a few watts), the focused light a laser produces is brighter than that of the sun or xenon-arc lamp on any given point.[1,2] Unlike normal light which quickly diverges, the most of the laser's light remains within an area only a meter across when measured two or three kilometers away.[3]

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[1]David Sliney and Myron Wolbarsht, Safety with Lasers and Other Optical Sources (New York, Plenum Press):1980, p. 1-56.

[2]John Brand and Tony Dedman, "The Laser Protection Program," Army Research, Development & Acquisition Bulletin, September-October 1989, pp. 1-5.

[3]U.S. Army, CATA, Directed Energy Warfare Awareness Training, Special Text 1-1, (Ft. Leavenworth, KS, CATA, November 1987), p. 3.

The laser's beam divergence (measured in milliradians, mrad)) determines how quickly the beam expands, which, in turn, determines the intensity of the beam (measured in square centimeters (cm^2)). A 1-mrad divergence produces a beam with a diameter of 1 meter at 1 kilometer. A laser with only a 0.5-mrad divergence would produce the same 1-meter circle at 2 kilometers. The "intensity" of both spots would be equal (ignoring battlefield and natural obscurants).

When relating divergence to laser weapons, if the laser weapons system has precise, accurate acquisition and targeting systems, a very small laser beam divergence is desirable because the power can be projected many kilometers. In terms of casualties, collateral risk to other soldiers and systems is small. Conversely, a wider divergence is desirable where the shooting process is not as precise or where there are multiple targets at close range. The divergence of a laser weapon's beam could be quickly switched from narrow to wide and back again.

Several misconceptions about lasers exist. Lasers are not the phasers as seen on televison. They can't yet destroy a plane with a single pulse of power. They can, however, burn out or disrupt optical sensors, including eyes. Also, lasers are not always visible, unlike the movie light sabers or science fiction's ray guns. The light may be invisible. (Nevertheless, it is still capable of harm. However, the light will not destroy everything in its path forever; fog, rain, smoke, and the air itself all diffuse the laser's light and reduce its concentration and power. Lasers just produce concentrated light; they can't make you sterile or stun you.

Light normally enters the eye from many directions and is painted over a relatively large image on the back of the eye. The eye is particularly vulnerable to laser light, because the intensity of laser light is much greater than that found in nature and the laser's light enters the eye with all the photons travelling parallel to each other. Therefore, the light can be focused to a very small point. Other factors also increase the eye's vulnerability. At night, the lens of the eye open larger which lets in more light, to include the laser's. Using binoculars also increases the light collected by the eye and increases the user's chance of laser light injury.

The effects of a laser depends on the laser's power, frequency (different parts of the eye pass or absorb different frequencies of light), pulse duration, and distance from the target. Light the enemy can see can be used to distract him temporarily or permanently blind him. Light that cannot be seen can still be absorbed by eye, burning its exterior and causing immediate pain or clouding. The invisible light may also pass through the eye so the back of the eye is damaged, destroying vision.

Sunglasses will not protect a soldier from the effects of a laser. Very dark sunglasses may block half of the light, but across the whole light spectrum. Typical laser protective goggles cut the amount of light to one part in thousands or millions, but only at the frequency of the laser. In 1989 the Army fielded ballistic laser-protective spectacles to protect soldiers from conventional small fragment eye injuries and laser light injuries. The spectacles effectively block the light from the currently fielded rangefinders and designators (ruby and Nd:YAG lasers).

APPENDIX B

LASER BIOEFFECTS

In this appendix, I discuss laser-caused biological effects of immediate military and medical consequence. I have not included occupational health effects caused by prolonged low-level exposure, photobiological effects at the cellular level, or the glare caused by the very bright light of a laser. Because most military lasers are in the visible or near infrared range, I only present the biological effects of these lasers. I excluded glare, despite its military utility, because it does not, itself, cause injuries. Laser-produced glare can, of course, temporarily degrade a pilot's vision and cause him to abort a mission or crash.[1]

The eye's structure makes it extremely vulnerable to the very bright light (brighter than any other natural or man-made light source) which lasers emit.[2] And, while the skin can be burned because of the intense concentration

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[1]For a technical treatment of glare, see the proceedings from the Lasers on the Modern Battlefield, (Published by LAIR) or D.H. Brennan's "Glare in Aviation" in Health Physics, May 1989.

[2]David Sliney and Myron Wolbarsht, Safety with Lasers and Other Optical Sources (New York, NY, Plenum Press, 1980).

of light, the primary target for lasers is the eye.[3] I first discuss the mechanism by which the laser damages the eye followed by the types of injuries expected on the battlefield.

INJURY MECHANISMS

As stated above, the eye is extremely vulnerable to lasers, particularly lasers using light which focuses on the retina. Unlike naturally encountered bright scenes, the scene is not projected broadly on the back of the eye. All of the laser's light entering the eye is concentrated on a single point on the rear wall of the eye, a process similar to using a magnifying glass to burn a hole in a piece of paper. And, continuing with the magnifying glass analogy, at certain frequencies, the eye acts likes dark paper, efficiently absorbing light and retaining heat, which in turn, burns.

Many factors contribute to eye injuries. The intensity of light entering the eye (measured in watts or joules) is just one factor affecting the biological response of the eye. The light's wavelength, the duration of exposure, variations in absorption or transmission of

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[3]Sliney and Wolbarsht report that from .2 - .4 J/cm^2 for a q-switched ruby laser is the skin threshold dose, while only .001 J/cm^2 is required to damage the human eye. The power levels to burn the skin in less than a second are very high and the soldier is warned by a sensation of warmth. Currently fielded adjunctive lasers can cause severe damage to eyes and in a billionth of a second--before the eye's natural defenses can operate.

light through the ocular media, retinal pigment, and choroid, the diameters of the pupil and the retinal image; and the spectral distribution of the light (after it is modified by the environment) contributes to potential effect.[4,5] There is significant biological variation between species and individuals within a species. The retina's threshold for laser damage is usually determined by what an observer can see with an ophthalmoscope some time after exposure.[6] Injury prediction is extremely difficult to do in a controlled environment.[7]

Lasers have three damage mechanisms: thermal-mechanical (acoustic transient), thermal, and photo-chemically induced injury.[8] The laser's pulse length strongly determines the damage mechanism. An acoustic transient (a strong tissue-disrupting pressure wave) accompanies localized heating with lasers that send pulses of energy in less than a microsecond.[9] Rangefinders and designators (termed q-switched) commonly have lasers with very short pulse lengths.

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[4]The choroid is the pigmented vascular tissue on which the retina is attached.

[5]U.S. Army, AEHA, Laser and Optical Hazards Course Manual, January 1982, p. 6-6.

[6]Laser and Optical Hazards Course Manual, p. 6-6.

[7]Sliney and Wolbarsht, p. 118 - 119.

[8]May also be referred to as a plasma injury.

[9]Franz Hillenkamp, "Laser Radiation Tissue Interaction," Health Physics, May 1989, p. 615. Pressure waves are known to travel at supersonic speed for several hundred micrometers. No test exists to determine which of the mechanisms causes the injury. The possible effects of chemical-reaction products are unknown.

As the pulse length increases from a microsecond to one millisecond, the acoustic transient component decreases in significance. Lasers with pulse durations between 100 microseconds to a few seconds generate thermally caused injuries. Energy (the laser light) is absorbed, causing a temporary temperature increase denaturing the proteins of the photoreceptor cells. The resulting injury can lead to the following:

- The cell may just cease to perform its vision-related function.
- The cell can die leaving a scar.
- The cell's loss of function can lead to a break in the blood-retinal barrier, allowing unnecessary substances to enter the eye. The resultant swelling, if the injury is on the retina, can be seen as distortion or loss of acuity.[10]

Visible light lasers with longer exposures appear to cause damage because of photochemical over-activity in the retina.[11] If the threshold is not exceeded, photoreceptor cells recover in weeks. If the threshold is exceeded, the photoreceptor cells die and color vision may be changed.[12]

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[10] John Marshall, "Structural Aspects of Laser-Induced Damage and Their Functional Implications," Health Physics, May 1989, p. 617-622.

[11] Laser and Optical Hazards Course Manual, p. 7-35.

[12] Marshall, p. 622.

Each mechanism is wavelength dependent. Ultraviolet light (less than 200 nanometers) is absorbed by the cornea. A laser using this frequency range causes corneal burns. While painful, this injury is usually temporary and heals in a day or two. As the wavelength increases (from 315 to 380 nanometers) more of the light passes through the cornea and is absorbed by the lens. The lens can become opaque. The opacity's duration and size depends on the exposure. Increasing the wavelength into the visible and infrared range (from 380 to 1200 nanometers) allows the light to strike the retina.[13] Rangefinders and designators commonly operate at 1,064 nanometers (a neodymium-YAG laser (Nd:YAG)) and 694 nanometers (the ruby laser).

TYPES OF INJURIES

Laser injuries can be temporary or permanent. They could include a burn on the cornea, small blind spots which go generally unnoticed, a loss of acuity which may improve with time, or bleeding holes inside the eye.

Retinal injuries result from visible and infrared over-exposures. If the focal spot is in the peripheral region and no bleeding occurs, the blind spot will, most likely, be unnoticed. If the focal spot is on the fovea (that portion of the eye with the greatest density of photoreceptor cells and where central vision is produced),

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[13] Sliney and Wolbarsht, p. 107.

a blind spot will appear in the center of vision. Human vision only has 20/20 resolution in the center and rapidly degrades off-axis from center. If the soldier is directly looking at a laser, the damage will be to the central vision. If the laser is fired from a designator within the view of the soldier, but the soldier is looking off to the side, only the peripheral region of the eye would be affected.

With minimal exposure, the soldier may only be flashblinded, that is, see an after-image. This effect could last a few seconds to a few minutes.[14] The rate it fades appears to depend on the intensity of the exposure and the environmental lighting. The impact of flashblinding depends on its location in the visual field, the visual task being performed, and the need for dark adaption.

At threshold exposures, eye damage can take as long as 48 hours to become visible. Thermal injuries are usually discrete and at the focal point of the exposure. Thermal-mechanical injuries are larger and leave permanent scars; recovery is expected, but can take from 11 to 30 days.[15,16] If, however, the laser's light strikes the optic nerve, total blindness could result.

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[14] Ibid, p. 139.
[15] Ibid, p. 137-138.
[16] Marshall, p. 619.

Above the threshold of exposure, lasers can produce a larger blind spot, the eye can swell which will blur vision, or hemorrhaging (bleeding) within the eye will occur. A permanent blind spot will result at the point of hemorrhage. The degree of vision loss depends on the type, location, and extent of the injury. Vision changes continue up to two months after exposure. There is no effective medical therapy.[17]

Laser injuries are commonly described using a system devised by John A. Wolfe, M.D, Captain, U.S. Navy. Wolfe suggests that retinal lesions be graded ophthalmoscopically.[18] A Grade I (or Wolfe Grade I, or WG I) is said to exist if retinal edema (swelling) is observed. A Grade II (WG II) injury exists if there is retinal necrosis (coagulation); WG III indicates a retinal hemorrhage, and a WG IV indicates a vitreous hemorrhage or a retinal hole. All WG injuries are irreversible visual injuries and result in some visual degradation. Wolfe Grades Pre-O, WG O, and WG Pre-1 have been added to denote laser effects below the permanent injury threshold.

The Division of Ocular Hazards, Letterman Army Institute for Research, has since tabulated the grade, the

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[17] V.-P. Gabel, et al., "Clinical Observations of Six Cases of Laser Injury to the Eye," Health Physics, May 1989, p. 705-710.

[18] John A. Wolfe, Laser Retinal Injury (LAIR Report No. 177), (Presidio of San Francisco, CA), June 1984, p. i.

dose, the visual effect, and the impact of laser exposure of foveal laser injuries. A WG Pre-0 has no visual effect and has no impact. A WG 0 is perceived as an immediate flash followed by deduced visual acuity (roughly 20/100). The effect is an inability to perform fine vision tasks for 15 to 20 seconds. A WG I is perceived the same as a WG 0, but enough energy enters the eye to cause a retinal burn. Recovery takes between 15 to 20 minutes. In a WG I injury, the soldier sees a similar flash but his vision does not improve for days. A WG II injury takes weeks for the soldier's vision to recover and results in a permanent defect. In a WG III injury, a retinal hemorrhage occurs. The soldier might see a red cloud as he looks through the blood. Recovery is slow (months) and vision only returns to 20/100 to 20/400. A more serious hemorrhage and even a vitreous hole occurs in a WG IV injury. The soldier will be permanently legally blind.[19]

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[19]Personal communication, LAIR, Division of Ocular Hazards. Also found in LAIR Briefing Slide # E1520-2. The dose (total interocular energy (TIE)) for each grade is WG Pre-0, <<ED(50); WG 0, ED(50)/2; WG Pre-I, ED(50); WG I, 2*ED(50); WG II, 5*ED(50); WG III, 10*ED(50); and WG IV, 50*ED(50). ED(50) is that dose where an effect is observed in 50 percent of the population studied.

APPENDIX C

U.S. AND SOVIET LASER SYSTEMS

HISTORY

Theodore Maiman made the first laser in 1960.[1] By the late 1960s, laser rangefinders were already on tanks.[2] Lasers are now part of many military applications; such as projectile guidance systems, rangefinders, and target designators. The military also uses lasers in target tracking, training, navigation, submarine detection, communications, and as components in many other products.[3]

The impact of currently deployed laser-assisted weapons is dramatic. In 1972, the U.S. Air Force destroyed the Thanha Hoa bridge with a laser-guided "smart" bomb, having failed 870 times using conventional explosives. In the Falklands in 1982, the extremely accurate delivery of British laser-guided munitions demoralized the Argentine force and significantly contributed to its surrender.[4] William Koenig, in his book Weapons of World War III, states that the laser "will probably have as far reaching an effect on warfare as have nuclear weapons."[5] The

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[1]Jeff Hecht, Beam Weapons, The Next Arms Race (New York, Plenum Press, 1984), p. 25.

[2]Bengt Anderberg, "The Low-Energy Laser Aimed at the Eye as a Potential Anti-Personnel Weapon," The Royal United Services Institute, Spring 1988, p. 35-39

[3]Witt, "Lasers in Military Roles," p. 4-16

[4]Mike Witt, "Lasers in Military Roles," Asian Defence Journal, March 1988, p. 4-16.

[5]William Koenig, Weapons of World War III, (London, Bison Books Ltd., 1981), p. 24.

U.S. and USSR each have over 30,000 lasers in their active inventories.[6] Because some of these lasers can damage the eye, they could also be used directly as weapons.

Between 1960 and 1978, the Pentagon spent one billion dollars to develop laser technology and by 1982 it had spent two billion dollars.[7] Observers estimate the USSR to have spent five billion dollars during the same period.[8] Laser systems and technology extend beyond NATO and the WARSAW Pact nations to the Third World.[9,10] Laser technology is now mature enough to make weapons.[11,12] The battlefield impact of the laser weapon has yet to be defined by the military.[13,14,15,16]

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[6]U.S. Army, TRADOC, Message, "Unclassified Directed Energy Threat," 8 November 1988, para. 1D.

[7]Hecht, Beam Weapons, p. 30.

[8]Koenig, Weapons of World War III, p. 41.

[9]William Fowler, "Lasers in the Field," Defence, November 1989, p. 868.

[10]"Imatronic's New Mini Lasers Take Advantage of Solid State Technology," Defence, June 1989, p. 463.

[11]John Alexander. "Antimateriel Technology," Military Review, p. 29-30.

[12]"Field Tests Approach for Bradley Laser System," Army Times, 9 October 1989, p. 36.

[13]The Army Tactical Directed Energy Warfare Master Plan, p. 1.

[14]Dave Maddox, "Directed Energy Warfare Requirements," briefing prepared for Industry Roundtable on Directed Energy, 28-29 September 1988.

[15]General M.R. Thurman, "Army Science Board 1988 Spring Meeting," briefing prepared by Cdr, TRADOC, 22 March 1988.

[16]The Army Tactical DEW Master Plan, pp 1-3.

COMMON LASER APPLICATIONS

Major uses for lasers today included projectile guidance systems, rangefinding, designating (and a combination of rangefinding and designating), illumination as a spot aiming projector, and training.[17] Rangefinding was the earliest application and is still the most common.[18]

Designators work on the principle that laser pulses are very short and the timing of the pulses can be varied tc [illegible]ate a code. A coded series of pulses is aimed at a target by a soldier on the ground, by a helicopter, or perhaps by another aircraft. A munitions is fired and "sees" the coded pulses reflected off the target and guides itself to it. Designators and rangefinder/designators are made by many companies.[19]

The successful use of wire and laser precision guided munitions (PGMs) during the 1973 Middle East War guaranteed their use in future battles. To counter the effectiveness of lasers, forces had to change conventional tactics; smoke, maneuver, suppressive fires, dust, weather, concealment, darkness, and terrain were all used as countermeasures.[20] However, there is no evidence that lasers themselves were used to blind enemy soldiers.

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[17] Witt, "Lasers in Military Roles," p. 4-15.
[18] Fowler, "Lasers in the Field," p. 864.
[19] Witt, "Lasers in Military Roles," p. 9-12.
[20] Kcenig, Weapons of World War III, p. 37-38.

Projectile-guidance systems have different launch platforms, guidance systems, and targets. Systems currently fielded include smart bombs, smart missiles, smart artillery rounds, beam-riding antiaircraft missiles, and laser-guided missiles.[21] The systems are sold worldwide. For example, the Swedish RBS-70 has been sold to Argentina, Australia, Bahrain, Indonesia, Ireland, Norway, Pakistan, Singapore, Sweden, Tunisia, the United Arab Emirates, and Venezuela.[22] Many other countries are obtaining inexpensive upgrades of existing dumb systems.[23]

Lasers, operating as beacons outside the visible spectrum, can be used with an electo-optical viewing system to see at night without being seen. The laser and the viewing system together are sold as laser illuminators. Systems using both low-light television (LLTV) and forward-looking infrared (FLIR) are examples of systems which can be used for invisible-laser applications.

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[21]Michael Gething, "Stand-off, First-shot Kills, Airborne Smart Weapons," Defence, November 1989, p. 896-874.

[22]Witt, "Lasers in Military Roles," states that such systems now fielded include the Paveway smart bomb (United States); the Maverick missile (United States); the AGM-65E (British version of the Maverick); Copperhead artillery round (United States); the Bofors FBS-70 beam riding antiaircraft missile (Sweden); Air Defense antitank system (ADATS) laser-guided missile (United States); and the Hellfire helicopter-borne missile (United States).

[23]Gething, "Airborne Smart Weapons", p. 869-874.

Laser spot projectors, both visible and invisible, can be put on pistols, rifles, or machine guns to improve their accuracy. Small solid state units fit into standard telescope rings. Even though lasers do not have the power to cause a laser injury, using just two AAA batteries can put a dot that can be seen on a target 100 meters away. This increased accuracy translates into increased conventional casualties. Over 40 countries have now obtained this type of system.[24]

Laser training systems now come in a variety of sizes and prices. Companies make simple small-arms units and sophisticated total battlefield systems like those used at the NTC. The Simfire (United Kingdom) tank crew training device is used by more than 35 nations. Systems for other vehicles are also in common use.[25]

LASER WEAPONS

Why does the U.S. (or anyone) want laser weapons? Do they really exist? What do they look like? What can they do? How will they be used? Why aren't they fielded yet? These and similar questions require answers.

PURPOSE

There are many reasons why the U.S., the Soviets, and others want laser weapons.[26,27] First, the laser

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[24]"Imatronic's New Mini-Lasers Take Advantage of Solid State Technology," p. 463.

[25]Richard Friedman et al., Advanced Technology Warfare, (New York, Harmony Books, 1985), p. 42-43.

[26]Hecht, Beam Weapons, p. 265-288.

weapon's "bullet" travels in a straight line at the speed of light. To hit a target, soldiers need only point and shoot, which will make training easier than with conventional weapons where the soldier must lead his target.

Second, using laser would save money. The need for expensive tracking equipment is negated. And, since light produces the effects, ammunition will not need to be produced, shipped, or moved for this system.

Third, using lasers would add to the element of surprise. It is a new weapon. Enemy aircraft, equipped with traditional electronic warfare warning devices, would not know when they where being tracked or targeted by a laser. Traditional countermeasures would be of little use.

Fourth, using lasers would be effective. Soldiers, fearing blindness, may protect themselves instead of acquiring targets. (Even jamming will break the normal engagement process when targeted.) Besides attacking the viewer, the system itself could warn the weapon holder that he is under observation (that an optic is being directed at him). Systems with protective devices limit the ability to see, a significant operational limitation.

Fifth, it could cause the enemy to make changes in his tactics, targeting, and acquisition process. To

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[27]Anderberg, "The Low-Energy Laser aimed at the eye as a potential Anti-Personnel Weapon," p. 38-39.

protect his soldiers, he would need to invest in laser warning and protection devices instead of lethal systems. An adversary might do nothing, however; this could negate his current investment in fielded electro-optics. La er protection is expensive, therefore it is unlikelv the enemy could afford to retrofit his entire inventory. If unprotected, the enemy may change his tactics to compensate--tactics which may make him vulnerable to attacks by other systems.

There are also good reasons why laser weapons have not been fielded. Technical reasons are given, but the driving issues appear to be limited resources and competing weapons programs. The national focus is now on high-energy, missile-killing lasers--the Strategic Defense Initiative (SDI).[28] There is also a strong lobby for existing technology and equipments, and there is an inertia built into the acquisition process which hinders the fielding of any new technology or systems.

There are many politicians, citizens, and some military leaders who do not want the U.S. to field blinding weapons.[29] Also, antisensor weapons (as opposed to laser-guided munitions) also have yet to prove themselves on the battlefield. Another part of the lack of support is caused

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[28]Friedrich Lindner, "Laser Weapons for Tactical Operations," Military Technology, June 1987. p. 125-126.

[29]"Field Tests Approach for Bradley Laser System," p. 36.

by the "hard kill" mentality.[30] What this means is that even if the weapon is effective, if it doesn't go bang, some soldiers just don't want it!

The bottom line, is that antisensor weapons have had limited funding.[31] Many experts honestly question the cost-effectiveness of these weapons when compared with other advanced and traditional technologies.[32] They criticize laser weapons as being too limited (just line-of-sight).[33] Experts say grenades and mortars will kill soldiers in fox holes or behind hills, but lasers will not.

Opponents of lasers point to a variety of technology problems: the unit cost is high; the size and weight of the power generator and the laser take up most of the available space in a tank or fighting vehicle; there is a large thermal signature which must be hidden, because current lasers are inefficient and much of the energy put into the laser is converted to heat and not laser light.[34] Also, finding and attacking optics requires an expensive acquisition and tracking system which increases cost, complexity, and size. And it is uncertain how often co-visibility (both weapons looking at each other) would occur between any two observers on any terrain. But, the

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[30]Alexander, "Antimateriel Technology," p. 29-30.

[31]"Field tests approach for Bradley laser system," p.36.

[32]David Morrison, "Tactical Laser Weapons: In For The Soft Kill?" Lasers and Optronics, May 1989, p. 22-24.

[33]Hecht, Beam Weapons, p. 274.

[34]Hecht, Beam Weapons, p. 267-284.

greatest technical problem is ensuring that enough light hits the sensor to guarantee jamming or destruction. Right now, the beam can be degraded by smoke, dust, fog, rain, and air turbulence.

The many variables (air absorption, sensor and laser geometry, sensor vulnerabilities and susceptibilities, etc.) make it difficult to model the system. This, in turn, makes it difficult to confidently perform a cost-benefit analysis as required by the acquisition process.

U.S. LASER WEAPONS PROGRAM

In the late 1960s, three U.S. services studied the possibilities of using high-energy lasers weapons. In 1973, the Air Force succeeded in shooting down drones using a 100-kiloWatt carbon dioxide laser. The Air Force also put a large carbon-dioxide laser into a Boeing 707. In 1983, this unit, called the Airborne Laser Laboratory NKC-135, successfully shot down a SIDEWINDER missile. Having demonstrated the concept's feasibility, the airborne laser program was closed down in 1984.[38]

The first Army programs were the mobile test unit (MTU) and the ROADRUNNER. The MTU was a 50-kiloWatt carbon dioxide laser developed in 1975 to shoot down aircraft. The ROADRUNNER used both carbon-dioxide and a Nd:YAG

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[38]Lindner, "Laser Weapons for Tactical Operations," p. 125.

(neodymium-doped-yttrium-aluminum-garnet) laser designed to attack enemy sensors. In 1981, work began on an air defense system called the Mobile Army Demonstrator. The program was suspended to concentrate laser research funds on the SDI.

In 1978, the Navy's high-energy laser program, SEALITE, successfully downed tubed-launched, optically tracked, wire-guided missiles (TOWs). The program's purpose was to develop a countermeasure to antiship, sea-skimming missiles. This laser program, dubbed the Mid-Infrared Advanced Chemical Laser (MIRACL), was also suspended to support the SDI program.[36]

Although Service-level, high-energy laser programs have ended, the military is still trying to field a laser weapon. Emphasis is on a low- or medium-energy laser to attack optics and electro-optics.[37] Infantry, armor, mechanized infantry, and air defense applications have been proposed. At the DoD level, the Joint Chiefs of Staff have directed the Army, Navy, and Air Force to integrate DEW into their force structures.[38]

To conform to this policy, the U.S. is developing a number of laser programs (listed below) and is currently

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[36] Ibid, p. 125-126.

[37] U.S. Army, CACDA, The Tactical DEW Master Plan, p. 2.

[38] U.S. Department of Defense, The Joint Chiefs of Staff, "The Integration of Directed-Energy Warfare into the Force Structure," 23 July 1989.

focusing on antisensor lasers and attacking sensors. The Army's stated function for these lasers is to jam or destroy electro-optical devices, not to destroy eyes.[39] However, it is obvious that effective antisensor systems will put enemy soldiers' eyes at risk.

Current Army Systems

The Stingray fits on a Bradley armored fighting vehicle and protects it by attacking the optics or electro-optics of enemy gunners. The cost is 500 thousand dollars to 1 million dollars per laser. Full-scale development will take 250 million dollars and 4 to 5 years.[40]

Cameo Bl ɔjay is a helicopter version of Stingray. Its deployment on the Apache is set for the late 1990s.[41]

Dazer is a 20-pound infantry weapon designed to "provide a soft kill against a variety of targets by attacking sensors, including television, night-vision devices, and personnel in armored vehicles."[42] Its primary target, however, is the eye. Designed to only flashblind the enemy for a minute or two, the Army concedes that soldiers too close to the Dazer could suffer permanent eye damage.[43] One manufacturer of a "Dazer system" uses

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[39] "Field Tests Approach for Bradley Laser System," p. 36.

[40] Ibid.

[41] Morrison, "Tactical Laser Weapons: In For The Soft Kill?" p. 23.

[42] Ibid

[43] "Army Designing Flash-Blindness Laser," Lasers & Optronics, March 1989, p. 19.

a crystal which can be tuned to different frequencies, making protection or countermeasures difficult.[44]

Jaguar is sponsored by the Armor School for the M1A1 (Block 3 Mod). Little else is known about this system. From looking at the previously discussed programs, one would guess this is a Stingray-like system on the Abrams tank.[45,46]

The Army Laser Weapons Technology program is even more obscure. It "provides for the development of near-term medium/high energy, wavelength-diverse laser weapons that are resistant to countermeasures" for close combat and air defense.[47]

There are also proposals to field other laser systems. The Engineer School has proposed putting Stingrays on the combat engineer vehicle (CEV). The Ordnance School requested a laser system to do explosive ordinance disposal (EOD). The Air Defense School and the Special Operations School have both considered laser applications. The CACDA is the proponent for a "laser bullet," a "flash bomb," and

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[44]Rawles, "Laser Weapons on the Battlefield," Defense Electronics, August 1989, p. 83. States solid state Q-switched system was tunable from 700 to 815 microns, 3.5 J/pulse at 20 Hz at 755 microns (70 Watts(W)); another system output 500 uJ in 33 nsec (18 mW).

[45]Maddox, "Directed Energy Warfare Requirements," briefing 28 September 1988.

[46]Orville Stokes, "Directed Energy Today," briefing 11 March 1988.

[47]Morrison, "Tactical Laser Weapons: In For The Soft Kill," p. 22.

"deception decoys." No specifications or fielding data are public.[48]

(As an aside, both the British and the Germans are working on lasers. The British showed an interest in using light as a weapon as early as WWII and have a strong laser industry.[49] It is very likely that they also have an antisensor program. British Brigadier Anderberg says there are "no officially known developments of anti-eye laser weapons. However, there are developments going on of optical and electro-optical countermeasure systems based upon the use of low-energy laser beams."[50] German programs began in the early 1970s and are now well advanced. A tracked air defense system is expected to be operational by 1998.[51])

U.S. Employment

Even as late as 1980, very little combat doctrine about the laser environment existed. Security classification of the technology led to the belief that lasers were a weapon of the far future. The Army now recognizes that DEW exists and has begun to address it doctrinally.[52]

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[48] Maddox, "Directed Energy Warfare Requirements," briefing 28-29 September 1989.

[49] Rawles, "Laser Weapons on the Battlefield," Defense Electronics, August 1989, p. 82.

[50] Anderberg, "The Low-Energy Laser aimed at the eye as a potential Anti-Personnel Weapon," p. 38.

[51] Christian Pochhacker, "German Antiaircraft Laser System," International Combat Arms, January 1988, p. 14-15.

[52] U.S. Army, FM 71-2, The Tank and Mechanized Infantry Battalion Task Force, May 1988, Appendix D, p. D-1.

Current doctrine does not advocate that soldiers should use rangefinders or designators as weapons. Effective flashblinding distances for U.S. systems against typical enemy armored vehicles are not published and are not part of combat training; only defensive doctrine exists.[53]

In 1986, prophetically highlighting the problem of this thesis, FM 17-95, Cavalry Operations, states,

> No army is known to have laser devices fielded for use specifically as weapons. However, laser target-designators and rangefinders are in the inventories of all major armies, and their numbers are increasing. Any of these laser devices can be used as a weapon. Laser weapons are effective against optical and electro-optical systems, specifically, eyes and fire-control sights.[54]

Field Manual 71-2, The Tank and Mechanized Infantry Battalion Task Force, makes the following tactical recommendations to operational planners.[55] The G2/S2 must dedicate reconnaissance assets and use the intelligence preparation of the battlefield (IPB) process to identify and target DEW threats. The G3/S3 must implement the appropriate DEW countermeasures into the unit's operational plan. Leaders should train soldiers to

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[53]Noncombat and training safety distances and procedures have been available since the early 1970s. Procedures to use lasers for their intended purpose, ranging and designation, of course, exist.

[54]U.S. Army, FM 17-95 Cavalry Operations, 14 February 1986, Appendix F, p. F-1.

[55]U.S. Army, FM 71-2. The Tank and Mechanized Infantry Battalion Task Force, September 1988.

protect themselves.[56] In FM 1-100, Army Aviation in Combat Operations, the aviator is told to use laser protective equipment and countermeasures (cover and concealment, smoke, suppression, and preemptive laser destruction operations).[57] Most field manuals, however, still fail to consider lasers.

Some military experts believe low energy lasers will be effective in close combat against tank crews, missile operators, artillery forward observers, commanders, and anyone who uses magnifying optics as the weapon of choice for ground troops against aircraft.[58] In the military journals, three tactical applications are postulated. Lasers could distract, flashblind, and blind.[59] As distractors, they could be used as a ruse, cause protection to be used degrading the enemy's abilities, and they could have a psychological effect. They can dazzle (deny useful vision while the weapon is used and for a short time thereafter). The Army is very concerned that helicopters flying nap-of-the-earth could be dazzled or flashblinded and crash. Blinding tank gunners

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[56]FM 71-2, May 1988, p. D-1.

[57]U.S. Army, Army Aviation in Combat Operations, FM 1-100, 28 February 1989, p. 3-30.

[58]Anderberg, "The Low-Energy Laser Aimed at the Eye as a Potential Anti-Personnel Weapon," p. 35-39.

[59]Ellis Madsen, "Defending Against Battlefield Laser Weapons," Military Review, May 1987, p. 29-33.

for even a few seconds could also be fatal.[40] The military advantages to effectively blind the enemy are obvious.

SOVIET LASER WEAPONS PROGRAMS

The Soviets have invested heavily in lasers for directed energy weapons.[41] As faas now known, they are ahead of the U.S. in laser technology and the pulsed-power technology necessary to power laser weapons.[42],[43] The 1989 Joint Military Net Assessment states, "The Soviets are developing technical improvements and operational concepts for use of laser devices against electro-optical sensors and visual acquisition systems."[44] The Soviets are "reported to have generators which can overload and burn out both optical and microwave sensors on the B-2."[45]

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[40] John Brand and Tony Dedmond, "The Army Laser Protection Program," Army RD&A Bulletin, September-October 1989, p. 1-5.

[41] Soviet Military Power 1989, p. 133.

[42] John Kiser, "Moscow's Red-Hot New Technologies," The Washington Post, 13 March 1989, p. D3.

[43] Yale Jay Lubkin, "Letters To The Editor," Defense Science, December 1989, p. 10.

[44] U.S., Department of Defense, The Joint Chiefs of Staff, FY 1989 Joint Military Net Assessment (Washington, D.C., 1989), p. 8-2.

[45] Lubkin, Defense Science, p.10.

CURRENT SOVIET SYSTEMS

The Soviets have been developing a hand-held laser similar to the U.S. Dazer.[66] Laser antiarmor and antiair systems are also believed to be in service using a wide radarlike beam, which finds the targets, and a narrow beam, which then tracks and attacks.[67] David Isby, author of Weapons and Tactics of the Soviet Army, states that the Soviets have weaponized a variety of laser technologies that are still in the pure science stage in the United States.[68]

Soviet Employment

The U.S. Army believes a Soviet-like force may use already deployed lasers against troops in battle.[69] In March 1987, it was made public that U.S pilots were "temporarily blinded by very powerful USSR laser systems aboard a USSR naval ship."[70] There are reports that lasers are being used tactically, both in Afghanistan and elsewhere.[71,72,73]

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[66] Martin Burkey, "Army Provides Peek at Secret Laser," The Huntsville Times, 23 January 1989, p. 3B.

[67] Hugh Lucas, "'Soviet Anti-Armor Laser in Operation,' says USA," Jane's Defence Weekly, 31 October 1987, p. 983.

[68] Rawles, "Laser Weapons on the Battlefield," p. 78.

[69] Message, "Unclassified Directed Energy Threat," p. 2.

[70] Rawles, "Laser Weapons on the Battlefield," p. 77.

[71] FM 71-1, p. F-1.

[72] National Public Radio, "All Things Considered," 11 Nov 89, three pilots reported to be flashblinded in the Pacific.

[73] "Soldiers Will Get Laser Protection," Omaha World Herald, 1 November 1987.

Lasers are not mentioned in Suvorov's text but he describes the "Axe Theory." The goal is to win; the Soviet will hit as hard and as quick with his best equipment to kill (and blind?) quickly.[74]

SUMMARY

Over 30,000 adjunctive lasers are in the inventories of both the U.S. and the USSR. Many other countries have them as well. While not intended as weapons, they have the ability to cause eye damage. The only requirement is intent. However, there is no documented evidence that the U.S. intends to do so.

Both the U.S. and the USSR can easily produce laser weapons. The Soviets are thought to have already fielded an antitank and antiair system. There is no documented evidence that the U.S. has done do.

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[74]Viktor Suvorov, Inside the Soviet Army (MacMillian Publishers, New York, NY, 1982), p. 159-162.

APPENDIX D

BEAM PROPAGATION CALCULATIONS

This appendix provides--

o The mathematical formula and postulated biological effects of the Lawrence Livermore National Laboratory (LLNL) Lasers As Air Defense Weapons model.

o The resulting tables.

o The spreadsheet cell definitions of the LLNL beam propagation.

The tables depict real and notional laser systems and calculate the laser energy (in uJ) entering the eye at 20-meter increments. In order to determine the range, add the numbers at the top of the column and at the left end of the row. For example, in Table D-1 (the U.S. M1 Rangefinder Observed Without Optics) energy entering the eye at 20 meters is 2,990 uJ and energy at 320 meters is 10.4 uJ.

In most of the tables, energy entering the eye is reduced to 1/100 of its maximum value to account for the many battlefield factors.[1] Protection is modeled by again reducing the energy by 1/100.

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[1]These tables do not say "Clear Day; No Obscurants" in the scenario and have a Bp of 31.7 and a Bs of 3170. Tables where Bp equals Bs are not degraded by 1/100 and represent the maximum beam propagation under ideal conditions for beam travel and target alignment.

LLNL Model

Total Interocular Energy (TIE) (J)

$$TIE = [(Bp/Bs)a_p(Bp)M^2\cos\Theta]\times[(E_1/A_s)(0.02)^{(R/VR)}]$$
$$= [\text{Effective pupil collection area}]\times[\text{target fluence}]$$

- Bp = Filtered (apparent) scene luminance (nits)
- Bs = True scene luminance (nits)
- a_p = Pupil area (cm^2)
- M = Optics magnification
- Θ = Angle between target line-of-sight and laser beam
- E_1 = Laser energy (J)
- A_s = Laser spot size at target (cm^2)
- VR = Visual range (km)
- R = Target range (km)

Figure D-1. Mathematical formula of LLNL Lasers as Air Defense Weapons Model

LLNL Model

Response to Damage (to Eyes)--Postulated

TIE	FOVEA	MACULA	Peripheral	
Pre-I	<5 uJ	<7 uJ	<10 uJ	No effect/beacon
WG I	5-15	7-20	10-30	Distracting and must be repeated > once per second
WG II	15-30	20-40	30-60	
WG III	30-150	40-200	60-300	
WG IV	150-450	200-600	300-900	Long-term casualty-A*
WG IV+	>450	>600	>90	Long-term casualty-B*

* Long-term casualty-A: Single hit demotivating;multiple\ hits are promptly disabling.

* Long-term casualty-B: Single hit is promptly disabling.

Figure D-2. LLNL Postulated biological effects.

Table D-1

Scenario: M1 Rangefinder, observed without optics
clear day, no obscurants

Injury: WG I, 450 m; WG II, 270 m; WG III, 190 m; WGVI, 90 m

Laser specs:	Power (J):	0.032			
	Div (mrad):	0.13			
	Angle:	0.0			
Environment:	Optic Used:	1.0		Pupil (cm²)	0.02
	Bp (nt)	3170		Vis Rg	10000
	Bs (nt)	3170			

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	115.9	27.9	11.9	6.4	4.0	2.6	1.9	1.4	1.0
20	2990	79.9	22.9	10.4	5.8	3.6	2.5	1.8	1.3	1.0
40	741.7	58.2	19.1	9.1	5.2	3.3	2.3	1.6	1.2	0.9
60	327.1	44.2	16.1	8.1	4.8	3.1	2.1	1.6	1.2	0.9
80	182.5	34.7	13.8	7.2	4.3	2.9	2.0	1.5	1.1	0.9

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.2	0.2	0.2
20	0.8	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.2
40	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.1
60	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.1
80	0.7	0.5	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.1

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
20	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
40	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
60	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
80	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0

Table D-2

Scenario: M1 Rangefinder, observed without optics

Injury: WG I, 50 m; WG II, < 30 m

Laser specs: Power (J): 0.032
Div (mrad): 0.13
Angle: 0.0

Environment: Optic Used: 1.0 Pupil (cm²) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	1.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0
20	29.9	0.8	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0
40	7.4	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0
60	3.3	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
80	1.8	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-3

Scenario: Chinese Rangefinder, observed without optics
clear day, no obscurants

Injury: WG I, 120 m; WG II, 70 m; WG III, 50 m; WGVI, 25 m

Laser specs:	Power (J):	0.12
	Div (mrad):	1
	Angle:	0.0

Environment:	Optic Used:	1.0	Pupil (cm^2)	0.02
	Bp (nt)	3170	Vis Rg	10000
	Bs (nt)	3170		

Total Intraocular Energy (uJ) Versus Distance

:	0	100	200	300	400	500	600	700	800	900
0 :	////	7.3	1.8	0.8	0.4	0.3	0.2	0.1	0.1	0.1
20 :	189.5	5.1	1.4	0.7	0.4	0.2	0.2	0.1	0.1	0.1
40 :	47.0	3.7	1.2	0.6	0.3	0.2	0.1	0.1	0.1	0.1
60 :	20.7	2.8	1.0	0.5	0.3	0.2	0.1	0.1	0.1	0.1
80 :	11.6	2.2	0.9	0.5	0.3	0.2	0.1	0.1	0.1	0.1

:	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0 :	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

:	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-4

Scenario: Chinese Rangefinder, observed without optics obscured battlefield

Injury: None

Laser specs:
- Power (J): 0.12
- Div (mrad): 1
- Angle: 0.0

Environment:
- Optic Used: 1.0
- Pupil (cm^2): 0.02
- Bp (nt): 31.7
- Vis Rg: 10000
- Bs (nt): 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-5

Scenario: Chinese Rangefinder, observed with 7x optics

Injury: WG I, 90 m; WG II, 50 m; WG III, 25 m

Laser specs:
Power (J): 0.12
Div (mrad): 1
Angle: 0.0

Environment:
Optic Used: 7.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	3.6	0.9	0.4	0.2	0.1	0.1	0.1	0.0	0.0
20	92.9	2.5	0.7	0.3	0.2	0.1	0.1	0.1	0.0	0.0
40	23.0	1.8	0.6	0.3	0.2	0.1	0.1	0.1	0.0	0.0
60	10.2	1.4	0.5	0.3	0.1	0.1	0.1	0.0	0.0	0.0
80	5.7	1.1	0.4	0.2	0.1	0.1	0.1	0.0	0.0	0.0

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2000	2100	2200	2300	2400	2500	2600	2700	2300	2900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-6

Scenario: Notional Rangefinder, observed without optics clear day, no obscurants

Injury: WG I, 550 m; WG II, 330 m; WG III, 240 m; WGVI, 110 m

Laser specs:	Power (J):	0.12		
	Div (mrad):	0.2		
	Angle:	0.0		
Environment:	Optic Used:	1.0	Pupil (cm^2)	0.02
	Bp (nt)	3170	Vis Rg	10000
	Bs (nt)	3170		

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	183.7	44.2	18.9	10.2	6.3	4.2	3.0	2.2	1.7
20	4737.	126.5	36.2	16.5	9.2	5.8	3.9	2.8	2.1	1.6
40	1175.	92.2	30.2	14.5	8.3	5.3	3.6	2.6	1.9	1.5
60	518.2	70.1	25.5	12.8	7.5	4.9	3.4	2.5	1.8	1.4
80	289.2	54.9	21.8	11.4	6.9	4.5	3.2	2.3	1.7	1.4

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.3
20	1.2	1.0	0.8	0.7	0.5	0.5	0.4	0.3	0.3	0.2
40	1.2	0.9	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.2
60	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2
80	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
20	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
40	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table D-7

Scenario: Notional Rangefinder, observed without optics

Injury: WG I, 110 m; WG II, 70 m; WG III, 50 m; WGVI, 25 m

Laser specs: Power (J): 0.12
Div (mrad): 0.1
Angle: 0.0

Environment: Optic Used: 1.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

:	0	100	200	300	400	500	600	700	800	900
0 :	////	7.3	1.8	0.8	0.4	0.3	0.2	0.1	0.1	0.1
20 :	189.5	5.1	1.4	0.7	0.4	0.2	0.2	0.1	0.1	0.1
40 :	47.0	3.7	1.2	0.6	0.3	0.2	0.1	0.1	0.1	0.1
60 :	20.7	2.8	1.0	0.5	0.3	0.2	0.1	0.1	0.1	0.1
80 :	11.6	2.2	0.9	0.5	0.3	0.2	0.1	0.1	0.1	0.1

:	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0 :	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

:	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-8

Scenario: Notional Rangefinder, observed without optics

Injury: WG I, 120 m; WG II, 70 m; WG III, 50 m; WGVI, 25 m

Laser specs: Power (J): 0.12
Div (mrad): 0.1
Angle: 0.0

Environment: Optic Used: 1.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	7.3	1.8	0.8	0.4	0.3	0.2	0.1	0.1	0.1
20	189.4	5.1	1.4	0.7	0.4	0.2	0.2	0.1	0.1	0.1
40	47.0	3.7	1.2	0.6	0.3	0.2	0.1	0.1	0.1	0.1
60	20.7	2.8	1.0	0.5	0.3	0.2	0.1	0.1	0.1	0.1
80	11.6	2.2	0.9	0.5	0.3	0.2	0.1	0.1	0.1	0.1

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-9

Scenario: Motional Rangefinder, observed with 3x optics

Injury: WG I, 350 m; WG II, 210 m; WG III, 150 m; WGVI, 70 m

Laser specs:
- Power (J): 0.12
- Div (mrad): 0.1
- Angle: 0.0

Environment:
- Optic Used: 3.0 Pupil (cm²) 0.02
- Bp (nt) 31.7 Vis Rg 10000
- Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	66.1	15.9	6.8	3.7	2.3	1.5	1.1	0.8	0.6
20	1705.	45.6	13.0	5.9	3.3	2.1	1.4	1.0	0.7	0.6
40	423.0	33.2	10.9	5.2	3.0	1.9	1.3	0.9	0.7	0.5
60	186.5	25.2	9.2	4.6	2.7	1.8	1.2	0.9	0.7	0.5
80	104.1	19.8	7.9	4.1	2.5	1.6	1.1	0.8	0.6	0.5

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.5	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
20	0.4	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
40	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
60	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
80	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
20	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
40	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
60	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-10

Scenario: Notional Rangefinder, observed with 7x optics

Injury: WG I, 760 m; WG II, 450 m; WG III, 330 m; WGVI, 150 m

Laser specs:	Power (J):	0.12		
	Div (mrad):	0.1		
	Angle:	0.0		
Environment:	Optic Used:	7.0	Pupil (cm²)	0.02
	Bp (nt)	31.7	Vis Rg	10000
	Bs (nt)	3170		

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	360.0	86.5	37.0	20.0	12.3	8.2	5.8	4.3	3.2
20	9285.	248.0	71.0	32.3	18.0	11.3	7.6	5.4	4.0	3.1
40	2303.	180.8	59.2	28.3	16.3	10.4	7.1	5.1	3.8	2.9
60	1015.	137.4	50.0	25.1	14.8	9.6	6.6	4.8	3.6	2.8
80	566	107.7	42.8	22.3	13.5	8.9	6.2	4.5	3.4	2.7

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	2.5	2.0	1.6	1.3	1.1	0.9	0.8	0.7	0.6	0.5
20	2.4	1.9	1.6	1.3	1.1	0.9	0.8	0.6	0.6	0.5
40	2.3	1.8	1.5	1.2	1.0	0.9	0.7	0.6	0.5	0.5
60	2.2	1.8	1.4	1.2	1.0	0.8	0.7	0.6	0.5	0.5
80	2.1	1.7	1.4	1.1	1.0	0.8	0.7	0.6	0.5	0.4

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1
20	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1
40	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1
60	0.4	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1

Table D-11

Scenario: Notional Rangefinder, observed with 13x optics

Injury: WG I, 1260 m; WG II, 790 m; WG III, 590 m; WGVI, 270 m

Laser specs:
Power (J): 0.12
Div (mrad): 0.1
Angle: 0.0

Environment:
Optic Used: 13.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	1241	298.5	127.6	69.0	42.5	28.4	20.0	14.8	11.2
20	32024	855	244.8	111.2	62.1	39.0	26.4	18.8	13.9	10.6
40	7943	623	204.1	97.8	56.1	35.8	24.5	17.7	13.2	10.1
60	3503	473	172.5	86.5	51.0	33.1	22.9	16.6	12.5	9.6
80	1955	371	147.6	77.1	46.4	30.6	21.4	15.6	11.8	9.2

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	8.7	6.9	5.6	4.6	3.8	3.2	2.7	2.3	2.0	1.7
20	8.3	6.6	5.4	4.4	3.7	3.1	2.6	2.2	1.9	1.7
40	7.9	6.4	5.2	4.3	3.5	3.0	2.5	2.2	1.9	1.6
60	7.6	6.1	5.0	4.1	3.4	2.9	2.4	2.1	1.8	1.6
80	7.3	5.8	4.8	4.0	3.3	2.8	2.4	2.0	1.8	1.5

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	1.5	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.6	0.5
20	1.4	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.5
40	1.4	1.2	1.1	0.9	0.8	0.7	0.7	0.6	0.5	0.5
60	1.4	1.2	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5

Table D-12

Scenario: Notional Rangefinder, observed with 13x optics & optical density 2 protection

Injury: WG I, 150 m; WG II, 90 m; WG III, 70 m; WGVI, 25 m

Laser specs:
Power (J): 0.12
Div (mrad): 0.1
Angle: 0.0

Environment:
Optic Used: 13.0 Pupil (cm²) 0.02
Bp (nt) 0.317 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	12.41	3.0	1.3	0.7	0.4	0.3	0.2	0.1	0.1
20	320.2	8.6	2.4	1.1	0.6	0.4	0.3	0.2	0.1	0.1
40	79.4	6.2	2.0	1.0	0.6	0.4	0.2	0.2	0.1	0.1
60	35.0	4.7	1.7	0.9	0.5	0.3	0.2	0.2	0.1	0.1
80	19.6	3.7	1.5	0.8	0.5	0.3	0.2	0.2	0.1	0.1

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-13

Scenario: Notional near-term weapon observed without optics

Injury: WG I, 1600 m; WG II, 1020 m; WG III, 770 m; WGVI, 370 m

Laser specs: Power (J): 24
Div (mrad): 0.08
Angle: 0.0

Environment: Optic Used: 1.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	2295.	551.9	235.9	127.6	78.5	52.4	37.0	27.3	20.7
20	59217	1581.	452.6	205.7	114.8	72.0	48.7	34.7	25.8	19.7
40	14689	1153.	377.3	180.8	103.8	66.3	45.4	32.6	24.4	18.7
60	6477.	876.0	319.0	160.0	94.2	61.1	42.3	30.7	23.1	17.8
80	3615.	686.7	272.9	142.5	85.9	56.6	39.6	28.9	21.8	16.9

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	16.1	12.8	10.4	8.5	7.0	5.9	5.0	4.2	3.6	3.1
20	15.4	12.3	10.0	8.2	6.8	5.7	4.8	4.1	3.5	3.1
40	14.7	11.8	9.6	7.9	6.6	5.5	4.7	4.0	3.4	3.0
60	14.0	11.3	9.2	7.6	6.3	5.3	4.5	3.9	3.3	2.9
80	13.4	10.8	8.8	7.3	6.1	5.2	4.4	3.8	3.2	2.8

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	2.7	2.4	2.1	1.8	1.6	1.4	1.3	1.1	1.0	0.9
20	2.7	2.3	2.0	1.8	1.6	1.4	1.2	1.1	1.0	0.9
40	2.6	2.3	2.0	1.7	1.5	1.4	1.2	1.1	1.0	0.9
60	2.5	2.2	1.9	1.7	1.5	1.3	1.2	1.1	1.0	0.9
80	2.4	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.9	0.8

Table D-14

Scenario: Notional near-term weapon observed without optics defocused to effect foot soldiers

Injury: WG I, 330 m; WG II, 290 m; WG III, 130 m; WGVI, 65 m

Laser specs: Power (J): 24
Div (mrad): 0.5
Angle: 0.0

Environment: Optic Used: 1.0 Pupil (cm²) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	58.8	14.1	6.0	3.3	2.0	1.3	0.9	0.7	0.5
20	1515.0	40.5	11.6	5.3	2.9	1.8	1.2	0.9	0.7	0.5
40	376.0	29.5	9.7	4.6	2.7	1.7	1.2	0.8	0.6	0.5
60	165.8	22.4	8.2	4.1	2.4	1.6	1.1	0.8	0.6	0.5
80	92.6	17.6	7.0	3.6	2.2	1.4	1.0	0.7	0.6	0.4

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
20	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1
40	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
60	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
80	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D-15

Scenario: Notional near-term weapon observed with 7x optics

Injury: WG II, 4000+ m; WG III, 3300 m; WGVI, 1890 m

Laser specs: Power (J): 24
Div (mrad): 0.08
Angle: 0.0

Environment: Optic Used: 7.0 Pupil (cm²) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	1.1E5	27043	11558	6252	3847	2569	1815	1336	1015
20	2.9E6	77509	22176	10079	5626	3529	2387	1702	1262	964
40	7.1E5	56502	18488	8858	5086	3247	2223	1599	1193	917
60	3.1E5	42922	15630	7840	4617	2996	2074	1504	1129	872
80	1.7E5	33650	13373	6982	4208	2771	1939	1427	1071	830

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	791.1	628.7	508.0	416.2	345.1	289.1	244.4	208.2	178.5	154.1
20	754.4	601.7	487.7	400.6	332.9	279.4	236.5	201.8	173.3	149.7
40	720.0	576.3	468.4	385.7	321.2	270.0	229.0	195.6	168.2	145.5
60	687.7	552.2	450.1	371.5	310.0	261.1	221.7	189.7	163.3	141.4
80	657.3	529.5	432.7	358.0	299.3	252.6	214.8	184.0	158.6	137.5

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	133.7	116.6	102.2	89.9	79.4	70.4	62.6	55.8	49.9	44.7
20	130.1	113.6	99.6	87.7	77.5	68.7	61.1	54.6	48.8	43.8
40	126.5	110.6	97.1	85.5	75.6	67.1	59.8	53.3	47.7	42.8
60	123.1	107.7	94.6	83.4	73.8	65.6	58.4	52.2	46.7	41.9
80	120.	105.	92.	81.	72.	64.	57.	51.	46.	41.

	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900
0	40	36	33	30	27	24	22	20	18	17
20	39	35	32	29	26	24	22	20	18	16
40	39	35	31	28	26	23	21	19	18	16
60	38	34	31	28	25	23	21	19	17	16
80	37	33	30	27	25	22	20	19	17	16

Table D-16

Scenario: Notional near-term weapon observed with 7x optics with optical density 2 protection

Injury: WG I, 1200 m; WG II, 760 m; WG III, 560 m; WGVI, 260 m

Laser specs: Power (J): 24
Div (mrad): 0.08
Angle: 0.0

Environment: Optic Used: 7.0 Pupil (cm²) 0.02
Bp (nt) 0.317 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	1124.0	270.4	115.6	62.5	38.5	25.7	18.2	13.4	10.2
20	29016	775.1	221.8	100.8	56.3	35.3	23.9	17.0	12.6	9.6
40	7197	565.0	184.9	88.6	50.9	32.5	22.2	16.0	11.9	9.2
60	3174	429.2	156.3	78.4	46.2	30.0	20.7	15.0	11.3	8.7
80	1771	336.5	133.7	69.8	42.1	27.7	19.4	14.2	10.7	8.3

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	7.9	6.3	5.1	4.2	3.5	2.9	2.4	2.1	1.8	1.5
20	7.5	6.0	4.9	4.0	3.3	2.8	2.4	2.0	1.7	1.5
40	7.2	5.8	4.7	3.9	3.2	2.7	2.3	2.0	1.7	1.5
60	6.9	5.5	4.5	3.7	3.1	2.6	2.2	1.9	1.6	1.4
80	6.6	5.3	4.3	3.6	3.0	2.5	2.1	1.8	1.6	1.4

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	1.3	1.2	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.4
20	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.5	0.4
40	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.5	0.4
60	1.2	1.1	0.9	0.8	0.7	0.7	0.6	0.5	0.5	0.4

Table D-17

Scenario: Notional near-term weapon observed without optics

Injury: WG I, 940 m; WG II, 590 m; WG III, 420 m; WGVI, 190 m

Laser specs:
- Power (J): 10
- Div (mrad): 0.1
- Angle: 0.0

Environment:
- Optic Used: 1.0
- Bp (nt) 31.7
- Bs (nt) 3170
- Pupil (cm²) 0.02
- Vis Rg 10000

Total Intraocular Energy (uJ) Versus Distance

:	0	100	200	300	400	500	600	700	800	900
0 :	////	612.1	147.2	62.9	34.0	20.9	14.0	9.9	7.3	5.5
20 :	15791	421.8	120.7	54.9	30.6	19.2	13.0	9.3	6.9	5.2
40 :	3917	307.5	100.6	48.2	27.7	17.7	12.1	8.7	6.5	5.0
60 :	1727	233.6	85.1	42.7	25.1	16.3	11.3	8.2	6.1	4.7
80 :	964	183.1	72.8	38.0	22.9	15.1	10.6	7.7	5.8	4.5

:	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0 :	4.3	3.4	2.8	2.3	1.9	1.6	1.3	1.1	1.0	0.8
20 :	4.1	3.3	2.7	2.2	1.8	1.5	1.3	1.1	0.9	0.8
40 :	3.9	3.1	2.5	2.1	1.7	1.5	1.2	1.1	0.9	0.8
60 :	3.7	3.0	2.4	2.0	1.7	1.4	1.2	1.0	0.9	0.8
80 :	3.6	2.9	2.4	1.9	1.6	1.4	1.2	1.0	0.9	0.7

:	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0 :	0.7	0.6	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.2
20 :	0.7	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.2
40 :	0.7	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.2
60 :	0.7	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.2

Table D-18

Scenario: Notional near-term weapon observed with 7x optics

Injury: WG I, 4000+ m; WG II, 2680 m; WG III, 2130 m; WGVI, 1150 m

Laser specs: Power (J): 10
Div (mrad): 0.1
Angle: 0.0

Environment: Optic Used: 7.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	29997	7211	3082	1667	1026	685	484.1	356.4	270.8
20	7.7E5	20669	5913	2687	1500	941	637	454.0	336.6	257.2
40	1.9E5	15067	4930	2362	1356	865	593	426.5	318.3	244.4
60	84640	11445	4168	2090	1231	799	553	401.2	301.3	232.5
80	47239	8973	3566	1861	1122	739	517	378.0	285.0	221.0

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	210.9	167.6	135.5	111.0	92.0	77.1	65.2	55.5	47.6	41.1
20	201.2	160.5	130.0	106.8	88.8	74.5	63.1	53.8	46.2	39.9
40	192.0	153.7	124.9	102.8	85.6	72.0	61.1	52.2	44.9	38.8
60	183.4	147.3	120.0	99.1	82.7	69.6	59.1	50.6	43.6	37.7
80	175.3	141.2	115.4	95.5	79.8	67.3	57.3	49.1	42.3	36.7

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	35.7	31.1	27.3	24.0	21.2	18.8	16.7	14.9	13.3	11.9
20	34.7	30.3	26.6	23.4	20.7	18.3	16.3	14.5	13.0	11.7
40	33.7	29.5	25.9	22.8	20.2	17.9	15.9	14.2	12.7	11.4
60	32.8	28.7	25.2	22.2	19.7	17.5	15.6	13.9	12.5	11.2
80	32.	28.	25.	22.	19.	17.	15.	13.	12.	11.

Table D-18

Scenario: Notional near-term weapon observed with 7x optics & optical density 2 protection

Injury: WG I, 680 m; WG II, 420 m; WG III, 300 m; WGVI, 140 m

Laser specs: Power (J): 10
Div (mrad): 0.1
Angle: 0.0

Environment: Optic Used: 7.0 Pupil (cm^2) 0.02
Bp (nt) 0.317 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	300.0	72.1	30.8	16.7	10.3	6.9	4.8	3.6	2.7
20	7737	206.7	59.1	26.9	15.0	9.4	6.4	4.5	3.4	2.6
40	1919	150.7	49.3	23.6	13.6	8.7	5.9	4.3	3.2	2.4
60	846	114.5	41.7	20.9	12.3	8.0	5.5	4.0	3.0	2.3
80	472	89.7	35.7	18.6	11.2	7.4	5.17	3.78	2.85	2.21

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	2.1	1.7	1.4	1.1	0.9	0.8	0.7	0.6	0.5	0.4
20	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.5	0.4
40	1.9	1.5	1.2	1.0	0.9	0.7	0.6	0.5	0.4	0.4
60	1.8	1.5	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.4
80	1.8	1.4	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.4

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1
20	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1
40	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1
60	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1

Table D-19

Scenario: Notional future weapon observed without optics defocused to attack foot soldiers

Injury: WG I, 630 m; WG II, 380 m; WG III, 270 m; WGVI, 130 m

Laser specs: Power (J): 100.0
Div (mrad): 0.5
Angle: 0.0

Environment: Optic Used: 1.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	244.9	58.9	25.2	13.6	8.4	5.6	4.0	2.9	2.2
20	6316	168.7	48.3	21.9	12.2	7.7	5.2	3.7	2.7	2.1
40	1566	123.0	40.2	19.3	11.1	7.1	4.8	3.5	2.6	2.0
60	690	93.4	34.0	17.1	10.1	6.5	4.5	3.3	2.5	1.9
80	385	73.3	29.1	15.2	9.2	6.0	4.2	3.1	2.3	1.8

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	1.7	1.4	1.1	0.9	0.8	0.6	0.5	0.5	0.4	0.3
20	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3
40	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.4	0.3
60	1.5	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.4	0.3
80	1.4	1.2	0.9	0.8	0.7	0.5	0.5	0.4	0.3	0.3

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
20	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
40	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
60	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
80	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1

Table D-20

Scenario: Notional future weapon observed without optics

Injury: WG I, 2280 m; WG II, 1520 m; WG III, 1160 m; WGVI, 580 m

Laser specs: Power (J): 100.0
Div (mrad): 0.1
Angle: 0.0

Environment: Optic Used: 1.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	6121.	1471.	629.0	340.3	209.4	139.8	98.8	72.7	55.3
20	1.5E5	4218.	1206.	548.5	306.2	192.1	129.9	92.7	68.7	52.5
40	39170	3074.	1006.	482.1	276.8	176.7	121.0	87.0	65.0	49.9
60	17273	2335.	850.6	426.7	251.3	163.1	112.9	81.9	61.5	47.4
80	9640.	1831.	727.7	380.0	229.0	150.8	105.5	77.1	58.3	45.2

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	43.1	34.2	27.6	22.7	18.8	15.7	13.3	11.3	9.7	8.4
20	41.1	32.7	26.5	21.8	18.1	15.2	12.9	11.0	9.4	8.1
40	39.2	31.4	25.5	21.0	17.5	14.7	12.5	10.6	9.2	7.9
60	37.4	30.1	24.5	20.2	16.9	14.2	12.1	10.3	8.9	7.7
80	35.8	28.8	23.6	19.5	16.3	13.7	11.7	10.0	8.6	7.5

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	7.3	6.3	5.6	4.9	4.3	3.8	3.4	3.0	2.7	2.4
20	7.1	6.2	5.4	4.8	4.2	3.7	3.3	3.0	2.7	2.4
40	6.9	6.0	5.3	4.7	4.1	3.7	3.3	2.9	2.6	2.3
60	6.7	5.9	5.1	4.5	4.0	3.6	3.2	2.8	2.5	2.3
80	6.5	5.7	5.0	4.4	3.9	3.5	3.1	2.8	2.5	2.2

Table D-20

Scenario: Notional future weapon observed without optics

(Continued)

	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900
0	2.2	2.0	1.8	1.6	1.5	1.3	1.2	1.1	1.0	0.9
20	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.9
40	2.1	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.9
60	2.1	1.9	1.7	1.5	1.4	1.2	1.1	1.0	0.9	0.9
80	2.0	1.8	1.6	1.5	1.3	1.2	1.1	1.0	0.9	0.8

	4000	4100	4200	4300	4400	4500	4600	4700	4800	4900
0	0.8	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4
20	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4
40	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4
60	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4
80	0.8	0.7	0.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4

Table D-21

Scenario: Notional future weapon observed with 7x optics

Injury: WG II, 5000+ m; WG III,4340 m; WGVI, 2690 m

Laser specs:	Power (J):	100.0			
	Div (mrad):	0.1			
	Angle:	0.0			
Environment:	Optic Used:	7.0		Pupil (cm^2)	0.02
	Bp (nt)	31.7		Vis Rg	10000
	Bs (nt)	3170			

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	2.9E5	72116	30822	16672	10260	6852.	4841.	3564.	2708
20	7.7E6	2.0E5	59136	26878	15004	9412	6367.	4540.	3366.	2571
40	1.9E6	1.5E5	49303	23623	13564	8660	5928.	4264.	3182.	2444
60	8.4E5	1.1E5	41682	20907	12314	7990	5531.	4011.	3012.	2325
80	4.7E5	89732	35660	18618	11221	7390	5170.	3778.	2854.	2213

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	2109.	1676.	1354.	1109.	920.3	770.9	651.6	555.0	476.1	410.9
20	2011.	1604.	1300.	1068.	887.6	744.9	630.6	538.0	462.0	399.2
40	1920.	1536.	1248.	1028.	856.4	720.0	610.5	521.6	448.5	388.0
60	1833.	1472.	1200.	991	826.6	696.2	591.3	505.8	435.5	377.1
80	1752.	1411.	1153.	955	798.1	673.4	572.8	490.7	423.0	366.7

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	356.6	311.1	272.6	239.8	211.8	187.7	166.9	148.8	133.1	119.3
20	346.9	302.8	265.6	233.9	206.7	183.3	163.1	145.5	130.2	116.7
40	337.5	294.9	258.8	228.1	201.7	179.0	159.3	142.3	127.3	114.3
60	328.4	287.2	252.3	222.5	196.9	174.8	155.7	139.1	124.6	111.8
80	319.6	279.8	245.9	217.1	192.2	170.8	152.2	136.0	121.9	109.5

Table D-21

Scenario: Notional future weapon observed with 7x optics

(Continued)

	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900
0	107.2	96.5	87.1	78.8	71.4	64.8	58.9	53.6	48.9	44.6
20	104.9	94.6	85.4	77.2	70.0	63.5	57.8	52.6	48.0	43.8
40	102.8	92.6	83.7	75.7	68.6	62.3	56.7	51.6	47.1	43.0
60	100.6	90.7	82.0	74.2	67.3	61.1	55.6	50.7	46.2	42.3
80	98.6	88.9	80.4	72.8	66.0	60.0	54.6	49.8	45.4	41.5

	4000	4100	4200	4300	4400	4500	4600	4700	4800	4900
0	40.8	37.3	34.2	31.4	28.8	26.5	24.4	22.5	20.7	19.1
20	40.1	36.7	33.6	30.8	28.3	26.1	24.0	22.1	20.4	18.8
40	39.3	36.0	33.0	30.3	27.9	25.6	23.6	21.7	20.0	18.5
60	38.7	35.4	32.5	29.8	27.4	25.2	23.2	21.4	19.7	18.2
80	38.0	34.8	31.9	29.3	26.9	24.8	22.8	21.0	19.4	17.9

Table D-22

Scenario: Notional future weapon observed without optics

Injury: WG I, 3040 m; WG II, 2110 m; WG III, 1630 m; WGVI, 850 m

Laser specs:
Power (J): 240.0
Div (mrad): 0.1
Angle: 0.0

Environment:
Optic Used: 1.0 Pupil (cm^2) 0.02
Bp (nt) 31.7 Vis Rg 10000
Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	14692	3532	1509	816.6	502.5	335.6	237.1	174.5	132.6
20	3.7E5	10123	2896	1316	734.9	461.0	311.8	222.3	164.8	125.9
40	94010	7379	2414	1157	664.4	424.1	290.3	208.8	155.8	119.7
60	41456	5606	2041	1024	603.1	391.3	270.9	196.4	147.5	113.8
80	23137	4395	1746	912	549.6	361.9	253.2	185.0	139.8	108.4

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	103.3	82.1	66.4	54.4	45.1	37.8	31.9	27.2	23.3	20.1
20	98.5	78.6	63.7	52.3	43.5	36.5	30.9	26.4	22.6	19.6
40	94.0	75.3	61.2	50.4	41.9	35.3	29.9	25.5	22.0	19.0
60	89.8	72.1	58.8	48.5	40.5	34.1	29.0	24.8	21.3	18.5
80	85.9	69.2	56.5	46.8	39.1	33.0	28.1	24.0	20.7	18.0

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	17.5	15.2	13.3	11.7	10.4	9.2	8.2	7.3	6.5	5.8
20	17.0	14.8	13.0	11.5	10.1	9.0	8.0	7.1	6.4	5.7
40	16.5	14.4	12.7	11.2	9.9	8.8	7.8	7.0	6.2	5.6
60	16.1	14.1	12.4	10.9	9.6	8.6	7.6	6.8	6.1	5.5
80	15.7	13.7	12.0	10.6	9.4	8.4	7.5	6.7	6.0	5.4

Table D-22

Scenario: Notional future weapon observed without optics

(Continued)

	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900
0	5.2	4.7	4.3	3.9	3.5	3.2	2.9	2.6	2.4	2.2
20	5.1	4.6	4.2	3.8	3.4	3.1	2.8	2.6	2.3	2.1
40	5.0	4.5	4.1	3.7	3.4	3.1	2.8	2.5	2.3	2.1
60	4.9	4.4	4.0	3.6	3.3	3.0	2.7	2.5	2.3	2.1
80	4.8	4.4	3.9	3.6	3.2	2.9	2.7	2.4	2.2	2.0

	4000	4100	4200	4300	4400	4500	4600	4700	4800	4900
0	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.9
20	2.0	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9
40	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9
60	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1.0	1.0	0.9
80	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	1.0	0.9

Table D-23

Scenario: Notional future weapon observed with 7x optics

Injury: WG I, 7000+ m; WG II, 6380 m; WG III, 5440 m; WGVI,3530 m

Laser specs:
- Power (J): 240
- Div (mrad): 0.1
- Angle: 0.0

Environment:
- Optic Used: 7.0
- Pupil (cm^2) 0.02
- Bp (nt) 31.7
- Vis Rg 10000
- Bs (nt) 3170

Total Intraocular Energy (uJ) Versus Distance

	0	100	200	300	400	500	600	700	800	900
0	////	7.1E5	1.7E5	73973	40013	24626	16445	11618	8554	6499
20	1.8E7	4.9E5	1.4E5	64508	36010	22590	15281	10896	8078	6171
40	4.6E6	3.6E5	1.1E5	56697	32555	20785	14229	10235	7638	5865
60	2.0E6	2.7E5	1.0E5	50178	29554	19176	13275	9628	7230	5580
80	1.1E6	2.1E5	85585	44684	25931	17737	12409	9069	6851	5312

	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	5062.	4023.	3251.	2663.	2208.	1850.	1563.	1332.	1142.	986.2
20	4828.	3850.	3120.	2563.	2130.	1787.	1513.	1291.	1108.	958.3
40	4608.	3688.	2997.	2468.	2055.	1728.	1465.	1251.	1076.	931.3
60	4401.	3534.	2880.	2377.	1983.	1671.	1419.	1214.	1045.	905.3
80	4206.	3388.	2769.	2291.	1915.	1616.	1374.	1177.	1015.	880.2

	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
0	855.9	746.6	654.1	575.5	508.3	450.5	400.5	357.1	319.3	286.3
20	832.5	726.8	637.4	561.2	496.0	439.9	391.3	349.2	312.4	280.2
40	809.9	707.7	621.2	547.4	484.1	429.6	382.4	341.4	305.6	274.2
60	788.1	689.3	605.5	534.0	472.6	419.6	373.8	333.9	299.0	268.4
80	767.0	671.4	590.3	520.9	461.4	409.9	365.3	326.5	292.5	262.8

Table D-23

Scenario: Notional future weapon observed with 7x optics

(Continued)

	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900
0	257.2	231.7	209.1	189.1	171.3	155.4	141.3	128.6	117.2	107.0
20	251.9	226.9	204.9	185.3	168.0	152.5	138.6	126.2	115.1	105.1
40	246.6	222.3	200.8	181.7	164.7	149.6	136.0	123.9	113.0	103.3
60	241.5	217.8	196.8	178.1	161.5	146.7	133.5	121.6	111.0	101.4
80	236.5	213.4	192.9	174.7	158.4	144.0	131.0	119.4	109.0	99.6

	4000	4100	4200	4300	4400	4500	4600	4700	4800	4900
0	97.7	89.6	82.1	75.3	69.2	63.6	58.5	53.9	49.7	45.9
20	96.1	88.0	80.7	74.0	68.0	62.5	57.6	53.0	48.9	45.1
40	94.4	86.5	79.3	72.8	66.9	61.5	56.6	52.2	48.1	44.4
60	92.8	85.0	77.9	71.5	65.7	60.5	55.7	51.3	47.3	43.7
80	91.2	83.5	76.6	70.3	64.7	59.5	54.8	50.5	46.6	43.0

	5000	5100	5200	5300	5400	5500	5600	5700	5800	5900
0	42.4	39.1	36.2	33.5	31.0	28.8	26.7	24.8	23.0	21.4
20	41.7	38.5	35.7	33.0	30.6	28.4	26.3	24.4	22.7	21.1
40	41.0	37.9	35.1	32.5	30.1	27.9	25.9	24.1	22.3	20.8
60	40.4	37.4	34.6	32.0	29.7	27.5	25.5	23.7	22.0	20.5
80	39.8	36.8	34.0	31.5	29.2	27.1	25.2	23.4	21.7	20.2

	6000	6100	6200	6300	6400	6500	6600	6700	6800	6900
0	17.9	18.5	17.2	16.0	14.9	13.9	13.0	12.1	11.3	10.6
20	19.6	18.2	17.0	15.8	14.7	13.7	12.8	12.0	11.2	10.4
40	19.3	18.0	16.7	15.6	14.5	13.6	12.6	11.8	11.0	10.3
60	19.0	17.7	16.5	15.4	14.3	13.4	12.5	11.6	10.9	10.2
80	18.8	17.5	16.3	15.2	14.1	13.2	12.3	11.5	10.7	10.0

```
A8: 'Scenario:
E8: 'Notional
Future Weapon,
Observed Without
Optics
H9: '  & Optical
Density 2
Protection
A10: 'Laser Specs:
E10: 'Power (J):
G10: 240
E11: 'Div (mrad):
G11: (F2) 0.1
E12: 'Angle:
G12: 0
A14: 'Environment
E14: 'Optic Used:
G14: 1
I14: 'Pupil (cm2)
K14: (G) 0.02
E15: 'Bp (nt)
G15: (G) 0.317
I15: 'Vis Rg
K15: (G) 10000
E16: 'Bs (nt)
G16: (G) 3170
A18: 'Total
Intraocular Energy
(uJ) versus
Distance
B20: '|C20: (T) 0
D20: (T) 100
E20: (T) 200
F20: (T) 300
G20: (T) 400
H20: (T) 500
I20: (T) 600
J20: (T) 700
K20: (T) 800
L20: (T) 900
A21: '   ---
B21: \-  (Repeat to
L21)
A22: (T) 0
B22: '|
C22: (F1) ' ////
D22: (F1)
($G$15/$G$16*$K$14*
$G$14*$G$14
*@COS($G$12)*$G$10/
(3.1416*(D$20+$A22)
*100*$G$11/1000))^2
)*(0.02^((D$20+$A22
)/$K$15)))*10^6
(Copy to all cells
L22)
A23: (T) 20
B23: '|
A24: (T) 40
B24: '|
A25: (T) 60
B25: '|
A26: (T) 80
B26: '|
B29: '|
C29: (T) 1000
D29: (T) 1100
E29: (T) 1200
F29: (T) 1300
G29: (T) 1400
H29: (T) 1500
I29: (T) 1600
J29: (T) 1700
K29: (T) 1800
L29: (T) 1900
A30: '   ---
B30: \-  (Repeat to
L30)
A31: (T) 0
B31: '|
C31: (F1)
($G$15/$G$16*$K$14*
$G$14*$G$14*@COS($G
$12)*$G$10/(3.1416*
(((C$29+$A31)*100*$
G$11/1000))^2)*(0.0
2^((C$29+$A31)/$K$1
5)))*10^6
 (Copy C31 to L35)
A32: (T) 20
B32: '|
A33: (T) 40
B33: '|
A34: (T) 60
B34: '|
A35: (T) 80
B35: '|
B38: '|
 (Tables for 2000
and 3000 meters use
same logic.  Change
the top row
reference, as with
C$20 and C$29, and
copy)
```

Figure D-3 Spreadsheet Cell Definitions

APPENDIX E

ENGAGEMENT DEFINITION

LIGHT VERSUS LIGHT

This scenario depicts an OPFOR battalion-size light force tactically deployed on two hilltops overlooking the U.S. force's avenue of approach. (See Figure E-1, designated objectives 1 and 2.) Six light, wheeled, armored vehicle batteries (BTRs) are attached. Three U.S. infantry squads have deployed to the south, east, and west observing the approaches to the OPFOR position. Two U.S. infantry companies are inserted by helicopters into the battle (30 minutes into the play) to positions held by two of the predeployed squads, both are one kilometer from the hilltop. There are no other attachments or detachments. The helicopters leave immediately and do not support the operation. No artillery support is available to either force.

The mission of the U.S. force is to secure the hilltops in the area within one hour. The operation is to be executed by a simultaneous attack on both hill. The terrain is tree-covered hills and open valleys (This simulation is played on Joint Readiness Training Center terrain.) No special command and control relationships exist; the battalion commander controls all U.S. forces.

The OPFOR withdraws as the Blue force takes both objectives. Fifty percent (46 of U.S. and 53 of OPFOR) of both combat forces becomes combat ineffective. Two of the armored batteries withdraw, two become combat ineffective, and the remaining are held three kilometers from the objectives.

The OPFOR only have one laser rangefinder located in the mortar battery. Mortars are deployed in two locations, in objective 2 and on a hill one kilometer north of objective 1. The mortars become combat ineffective almost immediately. The U.S. light forces attack, making good use of the foliage and terrain.

In summary, in examining the potential role of lasers, no force came within the effects zone of the currently fielded lasers. The OPFOR forces in objective 1 were completely combat-ineffective within 10 minutes. The use of any near-term laser rifle was judged to be minimal. In objective 2, half of the attacking force was within range of the OPFOR laser rifle, and half of those forces were directly attacking its likely location. I estimated 10 percent more U.S. casualties were possible. The OPFOR had no armor attached, so additional, proposed future weapons were not added. There was limited opportunity for the OPFOR to use the laser as a blinding system.

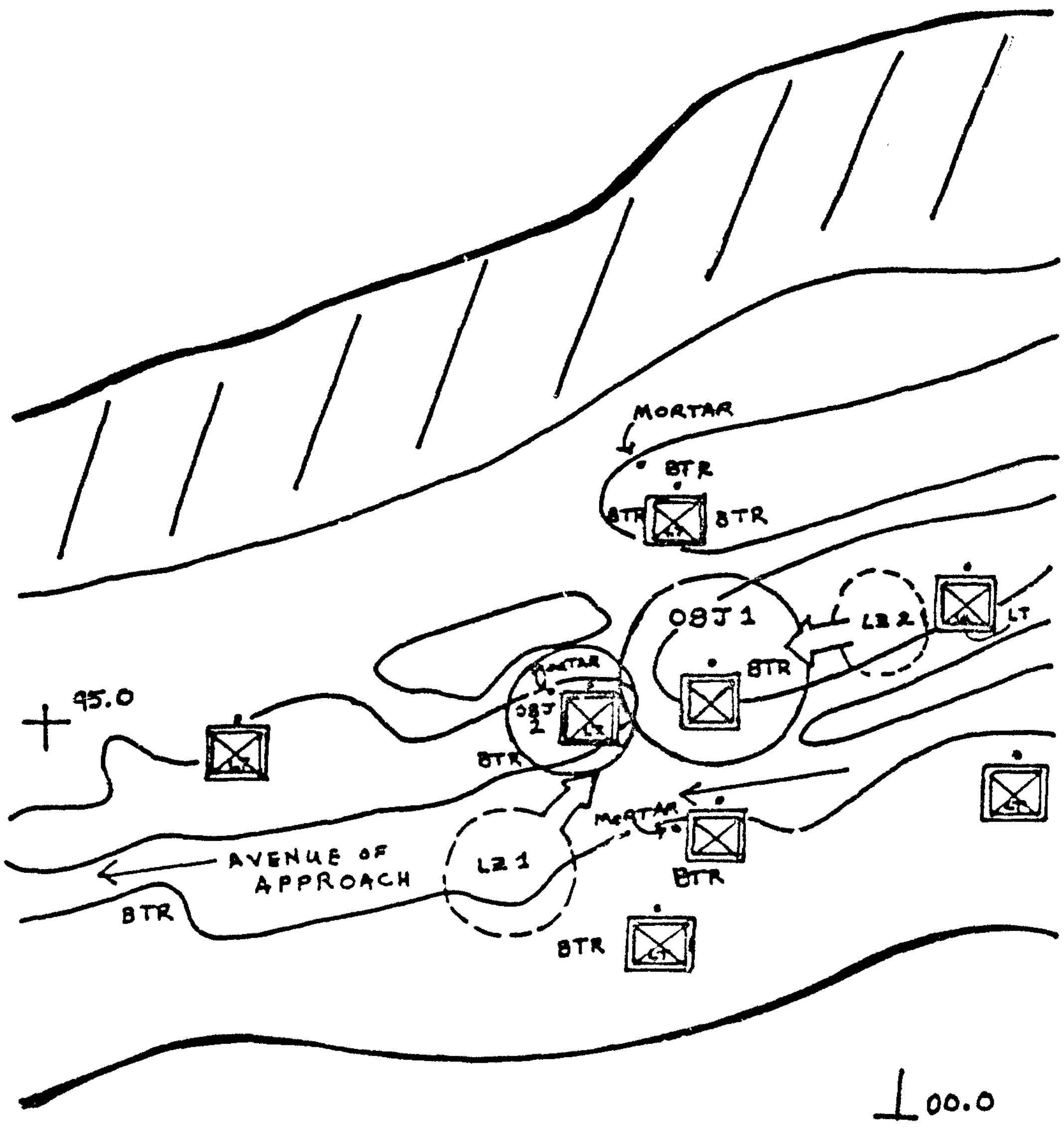


Figure E-1. Battlefield scenario, Light versus Light forces.

APPENDIX F

ENGAGEMENT DEFINITION

HEAVY VERSUS HEAVY

This scenario anticipates that threat forces will attack with an MRR orienting on a route of march in the northern part of the sector and that an advance guard or forward detachment will precede the main body. Task force scouts, GSR, and mortars will occupy the security zone between PLs BLUE and WHITE to conduct counterreconnaissance operations. Teams D and A will occupy deception positions DP5A and DP6A, respectively; team E will occupy BP 7; team B, BP 1; and team C, BP 3. On order, teams C and B will infiltrate forward to D1 and D2, respectively. Scouts and GSR will occupy OP positions throughout the depth of the sector. On attack of the MRR, teams C and B will delay from BPs D1, D2, D3, and D4 to defeat the advance guard MRB. After defeating this unit, teams C and B will move to BPs 3 and 1, respectively. When the remainder of the MRR advances to PL PURPLE, it will be attacked by all available indirect fire support and direct fire from team A in BP 6, team D in BP 5, and team C in BP 3; and there will be a counterattack on its southern flank by team B from BP 1 and the 151st Atk Hel Bn if available. Final destruction of the threat will occur in EA RED as he maneuvers to avoid the obstacles.[1] Combat support and combat service support is doctrinal.

---

[1]U.S. Army, CGSC, <u>Tactical Commanders Development Course Advance Book (Heavy Battalion Task Force</u> (89-5603), Academic Year 1989-1990, p. 105-110.

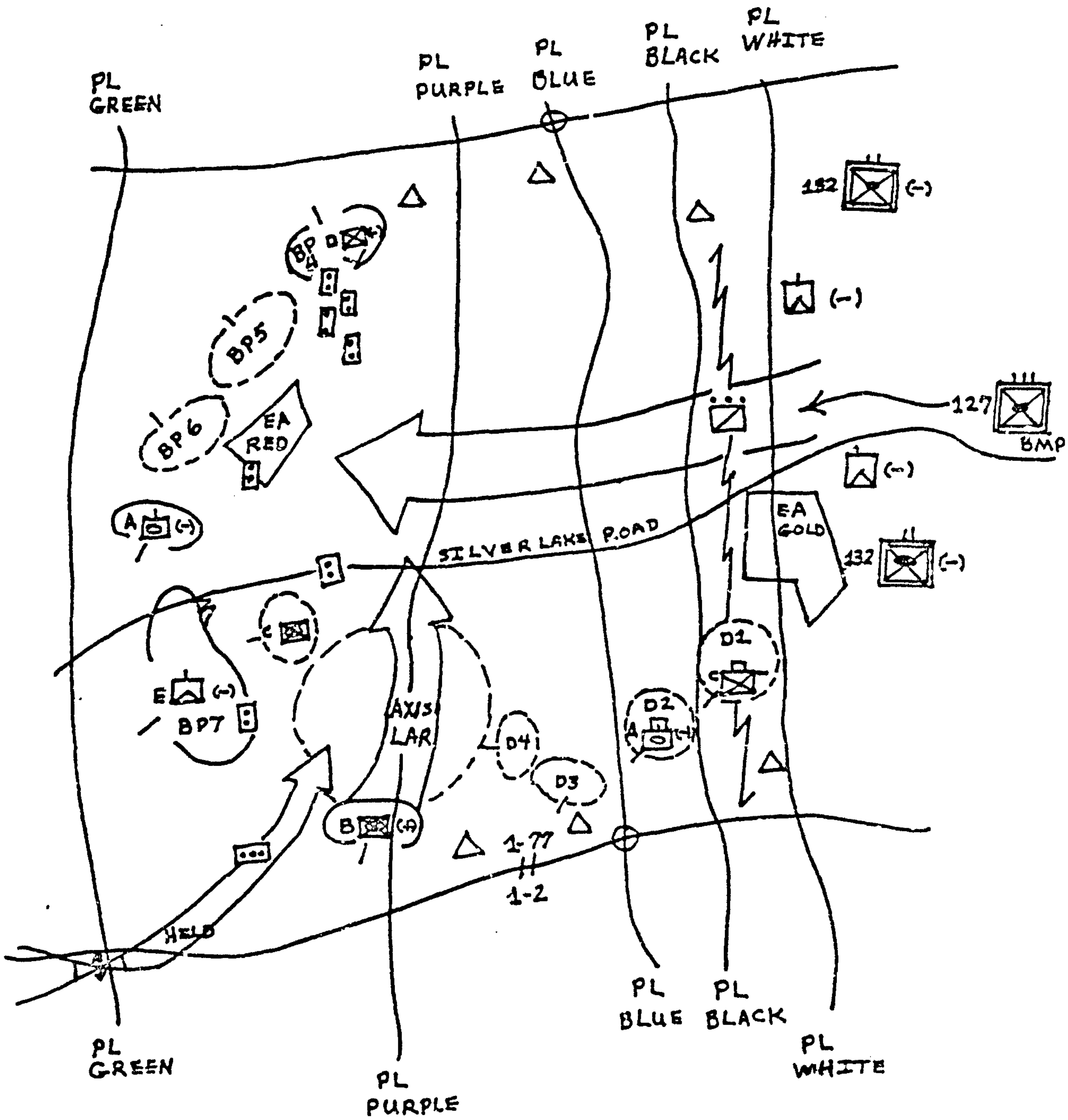


Figure F-1. Battlefield scenario, heavy versus heavy forces.

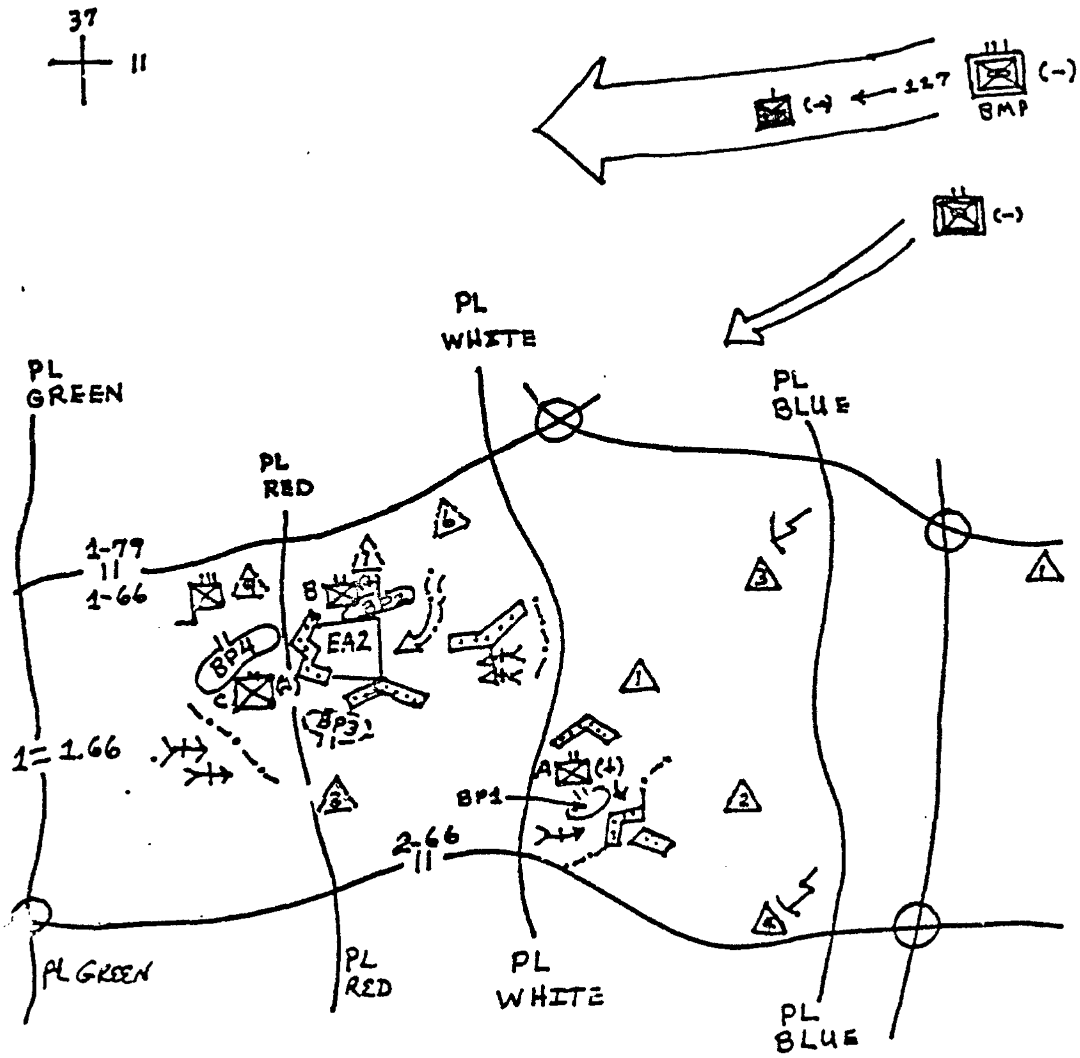
APPENDIX G

ENGAGEMENT DEFINITION

HEAVY/LIGHT VERSUS HEAVY

In this scenario (Figure G-1), there is a high probability that the threat will attack with an MRR (BMP) orienting on a rcute of march on the southern part of TF1-77 sector. This MRR attack could be preceded by an air assault or dismounted infiltration attack to siege key terrain in advance of the MRR in the U.S. sector. The U.S. force should also anticipate an advance guard or forward detachment in sector from the south as well. Therefore, we should develop courses of action that will defeat the threat forward of PL GREEN by using a strong enough force in the security zone to deny the threat intelligence and an MBA scheme of maneuver that can react to and defeat air assault/infiltration attacks. The U.S. force must also be arrayed in depth to ensure defeat of any advance guard or forward detachment that enters the defensive sector. Combat support and combat service support is doctrinal.[1]

[1]U.S. Army, CGSC, <u>Tactical Commanders Development Course Advance Book (Light Battalion Task Force</u> (89-05348), Academic Year 1989-1990, p. 104-110.



Co A (-)	Co B	Co C (-)	TF Control
FIST	FIST	FIST	SCOUTS
			1/A/21 MI (GSR)
			A/21 ENGR (-) (DS)
			MORTARS
			TOW
			1/A/2-441 ADA (V)
			B/4/A/2-441 ADA (S)
			TACD

Figure G-1. Battlefield scenario, heavy/light versus heavy forces.

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